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Implementation Case Study

Built Environment Resilience in Latin America and the Caribbean (BERLAC)

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Abstract Latin America and the Caribbean (LAC) is the second most disaster-prone region globally, with 1,534 disasters affecting approximately 190 million people during the first two decades of the twenty-first century. The region's vulnerability stems from its complex geographical and socio-economic conditions, characterized by rapid urbanization, inequality, poverty, and limited infrastructure resilience. Earthquakes, intensified by the region's location within the seismic "Ring of Fire," have caused substantial casualties, widespread displacement, and extensive damage to buildings and to the critical infrastructure, significantly impacting economic development and community livelihoods.

Recognizing the urgent need for effective disaster risk reduction (DRR) measures, UNESCO, with support from the Japanese Government, developed and implemented the Built Environment Resilience Latin America and the Caribbean (BERLAC) project. This pioneering three-year initiative aims to enhance disaster resilience by adopting a holistic and community-driven approach. Rather than relying solely on standardized approaches, BERLAC emphasizes the integration of international technical expertise with context-specific solutions, promoting resilience strategies that are sustainable and locally embedded.

Structured around four interconnected components—securing safer housing, enhancing school safety, retrofitting existing structures, and fostering risk-informed policy development—BERLAC not only strengthens local resilience but also establishes a scalable and adaptable model capable of bridging policy and practice. By actively engaging communities and stakeholders at all levels, BERLAC emphasizes capacity building, knowledge transfer, and participatory planning processes. This paper details BERLAC's methodologies, presents key findings from its implementation, and explores the policy implications derived from its successes and challenges, thereby contributing valuable insights to the global discourse on DRR and resilience strategies.

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1. INTRODUCTION

The 21st century has seen a convergence of climate change, rapid urbanisation, and deepening social inequalities, producing increasingly complex and interlinked disaster risks. Rising global temperatures intensify hydrometeorological extremes, degrade ecosystems, and threaten critical infrastructure, food security, and livelihoods. In many regions, climate-related stresses interact with political, institutional, and economic constraints, thereby heightening vulnerabilities—particularly in Least Developed Countries (LDCs) and Small Island Developing States (SIDS) (IPCC, 2022). Extreme events—often climate-related—disrupt economies and can trigger population displacement, entrenching inequalities and, in some contexts, contributing to social unrest (Bendito, 2020).

Urbanisation is a major driver of disaster risk. The concentration of people and assets in hazard-exposed areas heightens both exposure and vulnerability, particularly where land-use planning, zoning regulations, and early warning systems are weak or absent (UNDRR, 2023). Munich Re (2025) estimates that disasters caused approximately USD 131 billion in economic losses in the first half of 2025 alone. The February 2023 earthquakes in Türkiye and Syria illustrate the scale of human and economic impact: more than 50,000 fatalities and an estimated USD 39 billion in direct physical damages, much of it resulting from building collapse (World Bank, 2023). High-income countries tend to incur the largest insured losses due to higher asset exposure, while lower-income countries disproportionately bear the human toll, highlighting stark inequities in resilience capacity.

Latin America and the Caribbean (LAC) exemplifies these challenges. It is the second most disaster-prone region globally, having experienced 1,534 disasters that affected 190 million people during the first two decades of the twenty-first century. In the same period, the region recorded 92 major earthquakes—37 in Central America and 12 in the Caribbean—which accounted for 60% of disaster-related fatalities between 2001 and 2022 (UNDRR & OCHA, 2023). A recent region-wide assessment further highlights the scale of exposure: nearly one in five people (19.2%) in LAC is exposed to medium to high seismic hazard, 15.4% to high-intensity hurricane winds, and 9.8% to potentially damaging riverine floods (UNFPA & UNDRR, 2025). The region faces a wide spectrum of hazards—major earthquakes in Mexico, Chile, and Haiti; hurricanes devastating the Caribbean; and recurrent floods and landslides. Approximately three-quarters of global earthquake fatalities result from the collapse of inadequately designed or constructed buildings, rather than the seismic event itself (Jaiswal & Wald, 2008), underscoring the centrality of the built environment to disaster risk. Rapid and often unregulated urban expansion, coupled with inadequate enforcement of building codes, further magnifies both the probability of structural failure and the scale of potential losses.

The Sendai Framework for Disaster Risk Reduction 2015–2030 (Sendai Framework) embodies a global commitment to shift from reactive disaster response to comprehensive risk management, integrating prevention, preparedness, and resilience-building strategies (UNDRR, 2015). Despite advances in policy development, a persistent gap remains between commitments and practical implementation, driven by capacity constraints, governance challenges, and insufficient integration of scientific evidence into decision-making. Addressing this gap requires strategies that translate risk reduction objectives into tangible, resilient actions—actions that reduce vulnerabilities, strengthen preparedness, and enhance recovery capacity across sectors.

This paper uses the definition of resilience provided by UNDRR (2017): "The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions." In the context of the built environment, resilience encompasses the structural robustness of buildings and infrastructure, institutional readiness, and the integration of risk-informed policies into planning and investment. Since the built environment often accounts for the largest share of disaster-related losses—and constitutes a domain where engineering, policy, and community action intersect—it represents a critical leverage point for reducing disaster risk.

UNESCO integrates a resilience perspective across its DRR programmes and projects, assessing progress in terms of reduced vulnerabilities, strengthened preparedness, and improved adaptive capacity. Its support to Member States spans eight strategic areas: science, technology, and innovation; early warning systems; the built environment; education and school safety; cultural heritage protection; nature-based solutions; post-disaster response; and risk governance and social resilience (UNESCO, 2022). Within the built environment domain, UNESCO prioritises the translation of global frameworks into locally adapted solutions that can be scaled and sustained.

The BERLAC project, implemented by UNESCO in Cuba, the Dominican Republic, Guatemala, Haiti, Mexico, and Peru, seeks to bridge the persistent gap between DRR policy and practice. These countries were selected as representatives of earthquake-prone contexts in the LAC region, where the built environment faces critical challenges such as seismic housing vulnerabilities, school safety concerns, retrofitting needs, and policy shortcomings. BERLAC integrates scientific expertise with community-driven approaches, tailoring interventions to local hazard profiles, governance systems, and socio-economic conditions. Its multi-component strategy fosters collaboration among governments, technical institutions, and local stakeholders, advancing resilience principles and providing a replicable model for reducing disaster risk in urban and peri-urban settings.

This paper presents BERLAC as a case study in bridging global frameworks and local implementation. It describes the project's components (Figure 1) and methodologies, analyses outcomes across participating countries, and discusses implications for scaling resilience-building efforts in other hazard-prone regions. By situating BERLAC within both the global DRR agenda and the specific risk landscape of LAC, the paper contributes to an evidence-based understanding of how locally adapted, multi-stakeholder approaches can close the implementation gap in DRR.

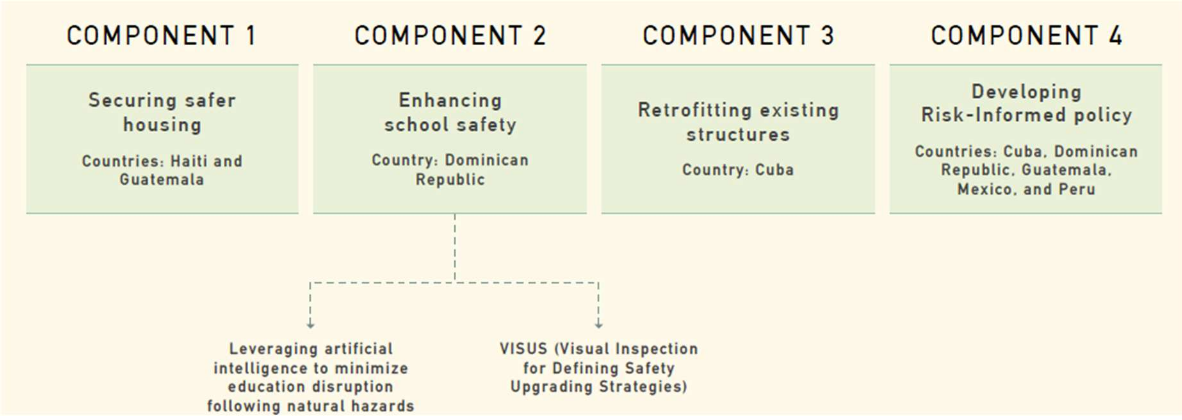

Figure 1. Components and countries covered by BERLAC

2. COMPONENT 1: SECURING SAFER HOUSING

Ensuring access to safe housing is essential for advancing disaster resilience and protecting lives in hazard-prone areas. In LAC, structural vulnerabilities in housing—often stemming from informal construction and limited enforcement of building regulations—remain a critical obstacle to achieving the Sendai Framework's global targets (World Bank Group & GFDRR, 2025). Poorly constructed homes not only increase disaster-related fatalities but also hinder recovery and perpetuate cycles of poverty.

The BERLAC project's first component addresses this problem through the development of locally adapted technical guidelines and the delivery of targeted capacity-building for masons and engineers. The anticipated outcome is a measurable reduction in structural failures, casualties, and associated economic losses

2.1 The Case of Haiti

Situated along the Enriquillo–Plantain Garden Fault Zone, Haiti is among the most earthquake-prone nations in the Caribbean. This seismic vulnerability is exacerbated by widespread informal construction and the use of substandard materials. The catastrophic earthquakes of 2010 and 2021 underscored the urgent need for systemic improvements in construction practices, materials regulation, and risk governance.

In the aftermath of the 14 August 2021 earthquake, Haiti was integrated into the BERLAC project to address these challenges. A review of existing post-earthquake assessments and stakeholder consultations in the affected areas revealed critical deficiencies in material quality and significant gaps in the technical capacity of local institutions. These findings informed the project's primary objective: the development of a National Manual of

Construction Materials Standards, in collaboration with the Bureau Haïtien de Normalisation (BHN), targeting reinforcing steel, cement, sheet metal, and structural timber.

The manual was developed in Haitian Creole and French to maximise accessibility and was designed to raise awareness among builders, engineers, and municipal authorities about quality standards for key construction materials. Its aim was both to improve technical knowledge and to reduce the persistent use of substandard materials that undermine structural safety.

Integration into the regulatory framework occurred through formal adoption at the municipal level. In participating five municipalities—Gonaïves, Cap-Haïtien, Les Cayes, Jérémie, and Anse-d'Hainault—mayoral directives now require municipal engineers to reference the manual's specifications when reviewing building permit applications. In several cases, the manual has also been incorporated into tender requirements for publicly funded construction projects, particularly schools and community facilities, aligning local practice more closely with internationally recognised standards.

Distribution was carried out through a dual print-and-digital approach. Approximately 2,000 printed copies were disseminated to municipal engineering offices, professional associations of engineers and architects, vocational training centres, NGOs, and community-based organisations engaged in reconstruction, and construction material suppliers.

To ensure effective uptake, the project organised five capacity-building workshops in the participating municipalities. These sessions trained 600 masons, 200 foremen, and 200 civil engineers (including 80 women) in seismic-resistant and paracyclonic construction techniques, coupled with training on risk and disaster management principles.

Early evidence of implementation includes:

- Policy and regulation. Municipal engineers in Les Cayes have used the manual's reinforcing steel specifications to reject substandard rebar during permitting.
- Construction practice. In Gonaïves, timber quality criteria from the manual guided the reconstruction of a school funded by an international NGO, ensuring compliance with moisture content and grading requirements.
- Material use. In Jérémie, trained masons applied the manual's cement mix guidelines in rebuilding cyclone-damaged homes, improving mortar strength and durability.
- Institutional capacity. Across all participating municipalities, engineers are now applying the manual's provisions in routine inspections, reinforcing long-term improvements in construction oversight.

In sum, the BERLAC project in Haiti has advanced from awareness-raising to practical, policy-linked action. By embedding quality standards into municipal permitting processes, distributing accessible technical guidance, and providing targeted training, it has begun to foster a culture of safer construction. This integrated approach offers transferable lessons for other earthquake-prone regions seeking to reduce vulnerabilities through education, regulatory alignment, and on-the-ground capacity building (UNESCO, 2023a).

2.2 The Case of Guatemala

Guatemala is highly exposed to multiple hazards, with seismic risk dominated by the Motagua and Chixoy–Polochic fault systems, compounded by active volcanism and recurrent hurricanes. Rapid urbanization has further intensified these risks, particularly in informal settlements and peri-urban areas.

A survey of experts across 170 municipalities revealed that, although Guatemala has seismic building codes, their enforcement is not mandatory. As a result, compliance remains limited, particularly outside the capital. This gap is most pronounced in small-scale housing, where the shortage of qualified personnel to conduct technical inspections during construction was identified as a critical weakness. Consequently, many housing projects remain highly vulnerable to structural failure during seismic events. The survey also highlighted progress at the policy level, particularly in the housing sector through the National Housing and Human Settlements Policy (PNVAH), where DRR principles were more explicitly integrated in the 2020 proposal compared to the 2002 version. However, translating these policy commitments into effective construction practices has remained a significant challenge.

To address these gaps, a locally tailored technical guideline for resilient small-scale housing was developed (UNESCO, 2023b). The guideline promotes context-appropriate solutions and strengthens municipal oversight mechanisms to improve compliance with safe construction practices.

Implementation included two workshops in 38 municipalities, training 150 municipal engineers and building inspectors in applying the guideline's principles. Training modules covered site selection, foundation, and structural detailing for seismic loads, and safe material handling. This process not only enhanced the technical skills of construction professionals but also increased institutional commitment to risk-informed housing practices.

Distribution involved printing over 1,000 copies, delivered to: municipal engineering and planning offices in high-risk areas; relevant national agencies within the Ministry of Communications, Infrastructure and Housing; vocational training centres and technical schools; universities offering architecture and civil engineering programmes; and NGOs. The guideline has been incorporated into the academic systems of several universities: Rafael Landívar University, Da Vinci University, and San Carlos University.

This multi-level approach strengthens the link between national policy objectives and on-the-ground implementation, creating a pathway for sustained resilience in the housing sector.

3. COMPONENT 2: ENHANCING SCHOOL SAFETY IN THE DOMINICAN REPUBLIC

School safety is a critical component of DRR and a fundamental aspect of safeguarding human capital development. Globally, educational institutions are susceptible to various hazards (e.g., hydrological and meteorological, technological, biological, and geological) that can disrupt learning, threaten lives, and impede socio-economic progress. Prioritizing safe, inclusive, and resilient learning environments is essential for achieving sustainable development, upholding children's rights, and ensuring educational continuity in crisis situations.

Component 2 is grounded in the understanding that ensuring school safety is both a protective measure and a strategic investment in resilience. It aligns with international frameworks such as the Comprehensive School Safety Framework (CSSF) 2022–2030, which adopts an all-hazards, all-risks approach to protecting children and education, offering governments a practical framework to make urgent progress across multiple facets of children's rights and the Sustainable Development Agenda. The CSSF emphasizes three pillars: safe learning facilities, school disaster management, and risk reduction and resilience education. Additionally, the Sendai Framework underscores the importance of reducing disaster risk in critical infrastructure, including educational facilities, to enhance resilience and ensure continuity (UNICEF, 2024).

In the context of the Dominican Republic, where various geological, hydrological, and meteorological hazards intersect with vulnerabilities in the education system, this component aims to strengthen institutional capacities, promote risk-informed planning, and foster intersectoral coordination for school safety. It emphasizes comprehensive approaches that integrate safe school facilities, effective risk reduction and preparedness education, and robust institutional mechanisms for emergency management within the education sector.

By fostering coordination between education authorities, disaster risk management institutions, local communities, and development partners, Component 2 seeks to institutionalize a culture of safety within the education sector and promote inclusive, equitable, and resilient learning environments across the Dominican Republic.

Within this context, Component 2’s objective is pursued through the utilization of two specific methodologies as shown in Figure 2.

3.1 Methodology 1: Leveraging Artificial Intelligence to Minimize Education Disruption Following Natural Hazards

A risk evaluation platform was developed to model the impact of seismic and water-related hazards on school operations and infrastructure. San Pedro de Macorís was selected as a case study to implement the methodology. Analyses were conducted in a rural area of Ramón Santana municipality and at the provincial level to compare results at different scales. This province was chosen due to the availability of data and its demographic similarities to the national level, making it representative of broader conditions in the Dominican Republic.

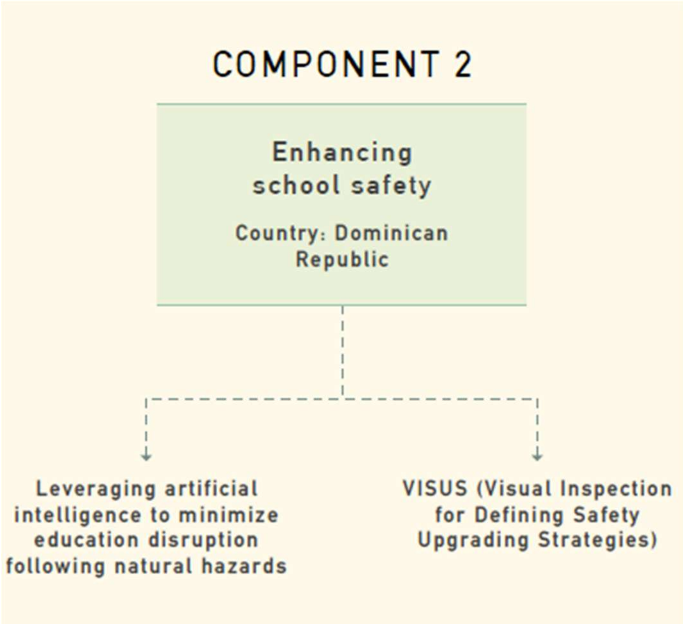

Figure 2. Methodologies applied under Component 2

Within the province, 288 school facilities were identified, comprising approximately 800 buildings that serve around 80,000 students. For seismic scenarios, school buildings were classified using the GLOSI approach, and each was assigned a seismic fragility function. For flood scenarios, building typologies were identified using GLOSI data, and vulnerability functions were assigned from the CAPRA platform (CAPRA, 2018).

The analysis also considered the road exposure model, including primary and secondary roads and the bridges connecting them. Road characteristics, such as type and recovery time from flooding, were identified based on the literature. For bridges, structural features—including spans, substructure, superstructure typologies, and materials—were determined using aerial images from the National Office for the Seismic and Vulnerability Assessment of Infrastructure and Buildings (ONESVIE). Based on these characteristics, typologies and fragility functions were assigned to each bridge using literature sources.

A method to model the recovery of school infrastructure, considering its interaction with the transportation network, was developed. This model integrates a Bayesian network (BN), Monte Carlo simulations (MC), and an Agent-Based model (AB). The BN identifies the probability of different operational states, which the MC uses to simulate conditions of operability. The AB model analyzes these simulations to calculate the interruption time of educational services. Two agents are defined: one for schools, prioritizing recovery based on student numbers, and one for transportation, sequencing interventions to support school recovery (D'Ayala et al., 2025).

The model was applied at rural and provincial levels for two seismic scenarios: a moderate event with a uniform PGA of 0.25g and an extreme event with a uniform PGA of 0.60g. For the rural area, the mean recovery time was 120 days under current infrastructure conditions, while at the provincial level, it was 205 days.

Three retrofitted conditions were analyzed: retrofitting bridges, retrofitting schools, and retrofitting both. Bridge retrofits focused on typology-specific improvements, including shear key enhancements, vertical element strengthening, and neoprene replacement. School retrofits addressed typology-specific needs, such as isolating non-structural walls, improving stiffness through additional elements, and jacketing existing structural components. For the provincial scenario, mean interruption times were reduced by 6, 19, and 33 days, respectively, for each retrofitted condition.

The networks were also evaluated under a flood scenario with a water depth of 0.25m. For the rural area, the mean recovery time was 74 days under current conditions, while at the provincial level, it was 127 days. A single retrofitted condition was analyzed for flood scenarios, involving wet-proofing systems for schools in flood-prone areas. This intervention included external plastering to make walls impervious, shields for openings with ground sills, and backflow valve installations. The retrofitting was applied uniformly to all buildings in susceptible areas. This reduced the interruption time by 35 days in rural areas and by 58 days at the provincial level.

These findings highlight the critical need for targeted retrofitting strategies to enhance resilience in the Dominican Republic's educational and transportation infrastructure, especially in the face of seismic and flood hazards (D'Ayala et al., 2025).

3.2 Methodology 2: VISUS (Visual Inspection for Defining Safety Upgrading Strategies)

The second methodology used: VISUS—Visual Inspection for Defining Safety Upgrading Strategies—is a science-based, multi-criteria safety assessment framework designed to support informed decision-making in the prioritization and implementation of school infrastructure risk reduction measures. Developed under the coordination of UNESCO and implemented in various national contexts, VISUS enables authorities to identify safety-critical deficiencies and optimize resource allocation for the protection of students, teaching personnel, and school infrastructure in a rational, efficient, and economically viable manner (Grimaz & Malisan, 2019).

In the Dominican Republic, a comprehensive VISUS assessment was conducted across 85 school complexes located in five departments: La Vega, Monseñor Nouel, Sánchez Ramírez, San Cristóbal, and San Pedro de Macorís. The evaluation encompassed 300 individual buildings (231 main structures and 69 ancillary buildings), covering a total of 131,429 m² of built-up area. These facilities serve 36,184 individuals across 1,152 classrooms. The methodological approach involved an in situ visual inspection guided by standardized criteria, with risk classification across five critical dimensions: location, structural global behavior, structural local behavior, non-structural elements, and functionality.

3.2.1 Location-Related Risks

Approximately 5% of the assessed schools are situated in areas exposed to geo-hazards such as landslides and rockfalls. Furthermore, a significant number of facilities were found to have unsafe or compromised access, particularly those adjacent to high-traffic roads, increasing the risk of injury during ingress or evacuation. In such cases, interventions may include hazard mitigation strategies (e.g., slope stabilization, retaining structures) or, where risks cannot be reduced to acceptable levels, strategic relocation.

3.2.2 Structural Global Behavior

Nearly 46% of the school buildings were found to exhibit substantial structural vulnerabilities under hazard scenarios. Although no structures were deemed at immediate risk of collapse, approximately one-third of the buildings suffer from notable deficiencies in material quality or maintenance. Key hazard-specific concerns include:

- Fire: 6% of the assessed buildings pose significant fire hazards due to combustible materials or a lack of fire prevention measures.
- Water: While no widespread water-related structural damage was observed, wooden structures may degrade under prolonged exposure to rainfall.
- Seismic risk: 20% of buildings present serious seismic deficiencies, with inadequate lateral load resistance and insufficient ductility.
- Wind: 17% of buildings are susceptible to significant damage or collapse in strong wind conditions, such as those associated with hurricanes.

Recommended interventions range from structural retrofitting to complete reconstruction, with temporary relocation of students and staff considered where necessary.

3.2.3 Structural Local Behavior

Local-level structural deficiencies were detected in 17% of buildings, with an additional 44% exhibiting localized risks to personal safety. Typical issues included falling masonry elements, unstable foundations, inadequate connections, and short column configurations susceptible to brittle failure. In hurricane-prone areas, roof detachment was also identified as a recurring concern. Localized retrofitting measures are strongly recommended and should be integrated within broader structural upgrading strategies when appropriate.

3.2.4 Non-Structural Risks

Non-structural hazards—identified in over 60% of the evaluated facilities—pose significant but often underestimated threats. These include falling ceiling components, unprotected elevated areas, unsecured furniture, open flame usage, and prevalent tripping hazards. Despite their frequency, such issues can generally be addressed through low-cost, high-impact interventions, making non-structural improvements a cost-effective priority for immediate action.

3.2.5 Functionality Constraints

Functionality-related deficiencies were documented in 33% of the buildings, primarily affecting emergency evacuation procedures. Overcrowded conditions, obstructed egress routes, and the absence of designated safe shelters limit the ability of schools to respond effectively during fires, floods, earthquakes, or windstorms. These issues compromise both the life safety of occupants and the continuity of educational services during emergencies.

3.2.6 Recommendations

The VISUS findings highlight the urgent need for a tiered intervention strategy, prioritizing high-risk facilities for retrofitting, relocation, or maintenance based on severity and cost-effectiveness. Addressing structural and non-structural risks in tandem will enhance the overall resilience of the education sector and protect critical human and infrastructural assets. The methodology provides a replicable model for evidence-based planning and resource optimization in school safety assessments. For detailed technical specifications, evaluation tools, and interpretation guidelines, readers are referred to the accompanying technical report (UNESCO, 2023c).

An important factor underpinning BERLAC's progress has been the recent high-level ministerial engagements in the Dominican Republic, which evidenced strong governmental commitment and multisectoral interest in embedding DRR—particularly school safety and infrastructure resilience—into national systems. These policy dialogues have contributed to consolidating political will and fostering coordinated action, thereby creating enabling conditions for a second phase of BERLAC as a sustainable, country-owned framework.

4. COMPONENT 3: RETROFITTING EXISTING STRUCTURES IN CUBA

The retrofitting of existing buildings is widely recognized as a cornerstone of DRR and climate resilience, particularly in regions with aging infrastructure with no maintenance, high exposure to multi-hazard risks, and historical gaps in the enforcement of construction standards. As urban populations expand and the frequency and intensity of hydrological and meteorological hazards increase (IPCC, 2022), together with persistent exposure to geological hazards, the need to enhance the structural performance of existing buildings becomes not only a technical priority but also a socio-economic and ethical imperative (Oliver-Smith et al., 2016).

Globally, millions of structures—especially critical infrastructure such as schools, hospitals, and administrative facilities—were constructed before the development of modern performance-based design codes or without consideration of hazard-specific loads such as earthquakes, high winds, or flooding. These buildings pose significant risks to life, public assets, and continuity of essential services. Retrofitting is an increasingly promoted solution, offering a cost-effective and less disruptive alternative to demolition and reconstruction. It allows infrastructure to remain operational while systematically reducing structural and non-structural vulnerabilities (Bruneau, 2022).

In Cuba, where seismic and hydrological, and meteorological hazards intersect with significant infrastructure exposure, particular attention was given to public buildings of educational and health importance, many of which were constructed using standardized prefabrication methods that do not align with contemporary hazard-resilience standards.

4.1 Case Study: "Orlando Fernández Badell" School in Cuba

Cuba, the largest and most densely populated island in the Caribbean, has a built environment that reflects both its cultural heritage and its past centralized planning approaches. However, many structures face technical and safety challenges due to design concepts from previous decades, material degradation, and insufficient maintenance. In collaboration with the National Centre for Seismological Research (CENAIS) and the Cuban Ministry of Education, the "Orlando Fernández Badell" school was selected for a detailed structural safety assessment.

The school was constructed using the Girón prefabricated concrete system, developed in the 1970s and widely deployed throughout Cuba. This structural typology is prevalent across the country and represents a significant share of the nation's educational infrastructure. Its evaluation revealed several vulnerabilities, and a retrofitting plan was developed and validated through a binational technical collaboration between Cuban and Japanese engineers. Experts from each country applied their own methodologies to diagnose weaknesses and propose retrofitting strategies, later sharing and cross-checking results. This exchange enriched the diagnostic process and increased the robustness and feasibility of the proposed solutions.

The key findings of the structural evaluation of the "Orlando Fernández Badell" school include:

- Systemic structural weaknesses in seismic load paths, particularly due to a lack of longitudinal shear capacity;
- Material and foundation degradation from environmental exposure and aging, requiring foundation strengthening;
- Non-structural hazards, such as unsecured fixtures and inadequate emergency egress, that pose significant life-safety risks;
- The added value of cross-national technical collaboration in adapting retrofitting approaches to local construction practices and constraints.
- The retrofitting plan includes the installation of shear walls, diaphragm stiffening, foundation reinforcement, and securing of prefabricated joints. These measures are

designed to significantly improve seismic performance while preserving architectural integrity and allowing continued educational use.

Importantly, the retrofit recommendations were formally shared with and endorsed by Cuban national authorities. The government is currently advancing initiatives to identify and mobilize the resources needed for implementation. The long-term goal is to extend the intervention to all schools built with the Girón prototype, thereby enhancing the safety and resilience of Cuba's educational infrastructure at scale. This case demonstrates that retrofitting is not only feasible but also essential in safeguarding critical infrastructure. Furthermore, it highlights how collaborative technical processes can strengthen national capacity and serve as a replicable model for other Caribbean and Latin American contexts facing similar seismic risks (UNESCO, 2023d, e).

5. COMPONENT 4: RISK-INFORMED POLICY DEVELOPMENT IN CUBA, DOMINICAN REPUBLIC, GUATEMALA, MEXICO, AND PERU

Risk-informed policy development is increasingly recognized as a fundamental enabler of DRR, sustainable development, and climate adaptation. By embedding risk assessments into the policy cycle, governments can proactively manage risk and protect both people and infrastructure from catastrophic losses. This approach enables more rational planning and resource allocation, ensures regulatory frameworks are rooted in scientific evidence, and guides long-term investments in resilient infrastructure (UNDRR, 2023; GCA, 2025).

In the context of seismic risk, engineering-based assessments and probabilistic hazard models have proven effective in guiding the formulation of building codes, land-use zoning, and critical infrastructure investments (Douglas et al., 2024). These assessment frameworks also facilitate the development of financial protection instruments—including insurance schemes, recovery funds, and retrofitting incentives—while aligning national legislation with international frameworks such as the Sendai Framework, the 2030 Agenda for Sustainable Development, and the Paris Agreement (United Nations, 2015; UNFCCC, 2015).

Moreover, risk-informed policies play a transformative role in raising public awareness and enhancing community preparedness. By linking governance, education, and urban planning, they help build a culture of safety and promote shared responsibility for risk reduction across society (UNDP, 2020). In highly exposed regions, these policies are particularly critical for addressing systemic vulnerabilities, such as informality in the construction sector, aging infrastructure, and weak enforcement of building regulations.

In a region like LAC, where rapid urbanization and complex hazard profiles intersect, risk-informed policy development offers a pathway to more resilient and equitable development outcomes. As highlighted in different studies, effective DRR governance hinges on the alignment between national institutions, technical standards, and the lived realities of vulnerable communities (Lavell et al., 2012).

5.1 Methodology

The study employed a four-step approach to examine building regulatory practices in the five countries:

- Desk research: A review of national laws, regulations, and administrative requirements was conducted for all five countries. This included analysis of published studies and media reports related to building regulations and their implementation in the region.

- Questionnaire survey: A comprehensive questionnaire was developed and distributed to governmental entities and private-sector professionals (including architects and engineers) in each country. The questionnaire sought to map national building regulatory frameworks and assess their practical implementation. Where additional information was required, it was obtained through follow-up consultations with experts, both by phone and in writing.

- Expert roundtable: A roundtable session was organized to facilitate inclusive discussions among the experts who responded to the questionnaire, ensuring representation from all five countries.

- Data processing and analysis: All collected information was translated into English, compiled by country, and systematically analyzed to identify key findings and comparative insights.

5.2 Key Findings from BERLAC Component 4

The main finding of the BERLAC Component 4 can be summarized as:

- Legal and regulatory frameworks exist but vary in enforcement: all five countries possess formal legal and regulatory frameworks for building codes, permitting procedures, and occupancy certification. These frameworks typically include defined responsibilities for regulatory authorities, steps for acquiring building permits, and mandatory inspections during and after construction. However, stakeholders across the five countries consistently reported gaps in enforcement, resulting in widespread construction without permits or final inspections, especially in informal or peri-urban settlements.

- Modifications after permit issuance pose structural risks: another widespread issue identified across countries is the unauthorized modification of structural designs after building permits have been granted. These changes often bypass professional review or re-approval, increasing the risk of unsafe construction and undermining the original seismic performance assumptions of the design.

- Informality and non-compliance undermine code effectiveness: across all five countries, authorities cited informal, self-built, or non-engineered constructions as a major source of seismic vulnerability. These buildings often use low-quality materials, bypass professional supervision, and do not comply with national building codes. This reflects a broader issue of risk governance in many LAC countries, where regulatory systems operate in parallel with large informal construction sectors.

- Qualification standards exist, but are frequently circumvented: most countries enforce regulatory requirements for licensed engineers, architects, inspectors, and contractors. However, enforcement is inconsistent. Building owners frequently hire unlicensed or underqualified personnel to reduce costs, compromising safety and contributing to systemic risk accumulation. In some cases, material suppliers and site supervisors are also unregulated, which further reduces quality control.

- Unique features in Cuba's System: Cuba’s building regulatory system differs notably due to its centralized governance and state-led construction management. While legal frameworks are comparable in form to those in the other countries, implementation mechanisms are more tightly controlled, and informal construction is more limited due to centralized planning. However, this system presents its own constraints in flexibility and innovation adoption.

5.3 Recommendations for Strengthening Building Regulation Implementation

The recommendations of BERLAC Component 4 for the effective implementation of building regulations were structured around four approaches, each targeting key actors in the construction process: owners, designers, and contractors (including site engineers, foremen, workers, material manufacturers, and suppliers).

Each of these actors plays a critical role in ensuring the safe and successful completion of a project. However, as illustrated in Figure 3, if any one of them fails to comply with regulations or fulfill their responsibilities, they become the weak link that compromises the structure, leaving it vulnerable to earthquake damage.

Three of these approaches follow a progressive pathway—beginning with voluntary compliance and advancing toward legal enforcement, to be applied when willingness and promotion alone do not succeed (UNESCO, 2023f).

1. **Own willingness** refers to the situation when the main stakeholders voluntarily and proactively comply with the building regulations without external pressure or enforcement.

2. **Promoting own willingness** refers to actively encouraging the main stakeholders to comply with the building regulations without pressure, leading to proactive adherence. For example, in several countries, complex, unclear, and time-consuming procedures often deter owners from applying for building permits. In such instances, simplifying and making the procedures more transparent could be instrumental as an example of promoting one’s own willingness.

3. **Pressure by other stakeholders** to follow the regulations refers to when external entities are actively encouraging or compelling the main stakeholders involved in the

construction process to follow the building regulations. For example, financial institutions or service providers such as water, sewage, may request building permits from the owner before delivering their services.

4. **Regulation by authorities** refers to a set of rules, standards, or guidelines established by governing bodies or regulatory agencies. These regulations are designed to govern and ensure compliance with legal requirements. For example, regulatory authorities might enforce a requirement for owners to exhibit a copy of the building permit visibly at the construction site.

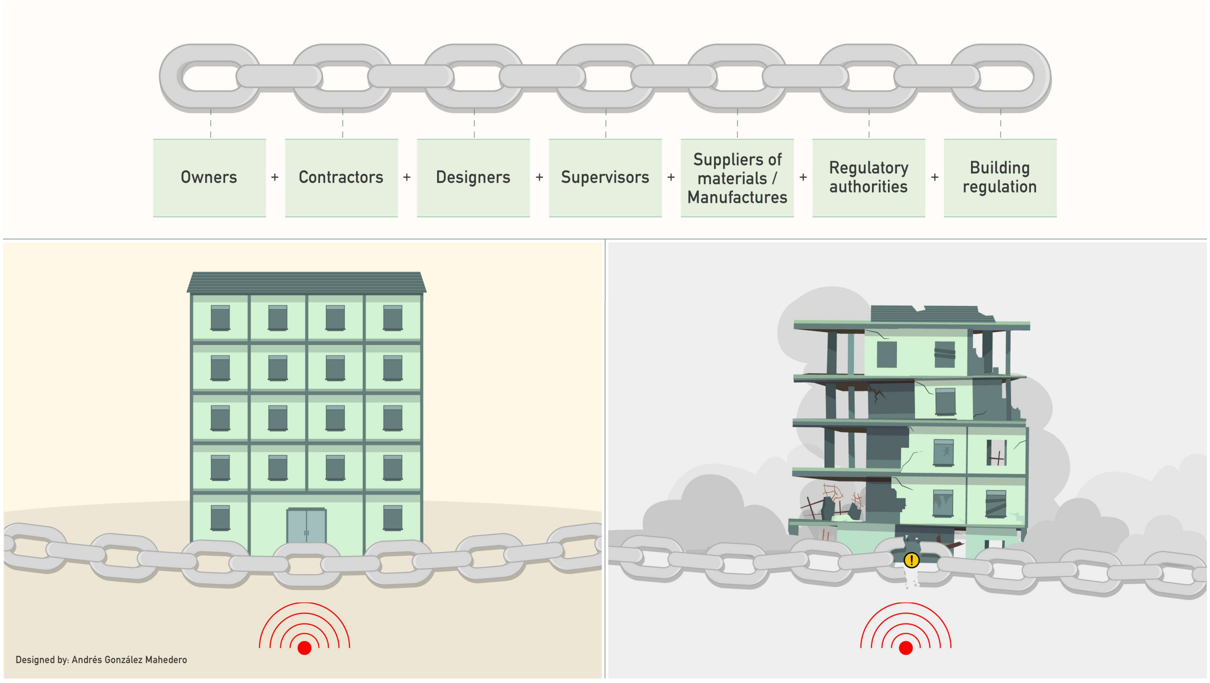

Figure 3. Key actors in the construction process

6. CONCLUSIONS

The BERLAC initiative illustrates that building disaster resilience in the LAC region requires an integrated approach, combining robust engineering solutions with governance, institutional capacity, and community engagement. Structural safety alone is insufficient without the proper mechanisms to ensure enforcement and accountability. By aligning engineering practices with policy and regulatory frameworks, BERLAC bridges the critical gap between technical knowledge and real-world implementation, enabling more effective DRR outcomes.

A key contribution of BERLAC is the development of localized technical standards, such as the national manual of construction materials in Haiti and the housing inspection guideline in Guatemala. These tools address context-specific vulnerabilities by translating national and international engineering standards into accessible, actionable practices. By tailoring technical guidance to local realities, the project enhances the feasibility and uptake of safer construction methods across formal and informal sectors.

The systematic application of risk assessment frameworks such as VISUS and the AI-based Bayesian-Monte Carlo-Agent model in the Dominican Republic demonstrates the importance of data-driven prioritization. These methodologies enable planners and decision-makers to identify vulnerabilities, simulate hazard impacts, and optimize resource allocation. Their use in school infrastructure planning underscores the value of multi-criteria tools in informing both technical and policy responses.

Furthermore, BERLAC highlights the multiplier effect of institutional capacity building, which ensures that technical improvements are embedded not just in structures, but in people and institutions capable of sustaining resilience over time.

Despite the presence of legal and regulatory frameworks for construction safety in the five participating countries, enforcement remains a persistent challenge—particularly in informal settlements. BERLAC's findings underscore the need to complement regulation with mechanisms that promote voluntary compliance, streamline permitting procedures, and leverage peer and institutional pressure to foster a culture of safety. Informal construction must be addressed through inclusive policies and locally tailored technical support.

Cross-border collaboration has also emerged as a catalyst for innovation. Technical exchanges between Cuban and Japanese engineers, for instance, enhanced the design and feasibility of retrofit solutions for Girón-type buildings. Such partnerships facilitate knowledge transfer, accelerate problem-solving, and promote adaptive innovation in the face of complex, evolving hazards.

Finally, the project emphasizes the need for scalable multi-hazard retrofitting strategies. Combined retrofitting interventions addressing seismic and flood risks, as piloted in the Dominican Republic, reduced school service interruption by several weeks. As climate and seismic risks intensify, integrating multi-hazard approaches into infrastructure investment strategies is not only prudent but essential for safeguarding development gains.

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COMPETING INTEREST DECLARATION

The authors have no competing interests to declare that are relevant to the content of this manuscript.

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