Integrating AI-Driven Strategies for Disaster Preparedness in the Philippines: Retrofitting Old Buildings as Smart Evacuation Centers

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Abstract: This study analyzed the strategies of adapting old public school buildings as evacuation centers to climate change by balancing structural retrofitting with modern AI-driven systems towards enhanced disaster resilience, considering safety, spatial, and energy efficiency. The growing occurrence of natural disasters such as floods and mudslides exposes the insufficiency and ineffectiveness of existing evacuation centers, which often lack the spatial requirements, structural integrity, and safety measures. To address this problem, 30 public school buildings were assessed while looking into modern retrofit techniques through an evidence-based framework. Mixed methods were used, conducting interviews with former evacuees in flood-prone areas, site and architectural survey compared with standard designs, and case analysis of successful building retrofits with AI and smart integration within the context of the Sendai Framework, Build Back Better. Results suggest that retrofit and smart-integrated methods are replicable within the Philippine context, with an ever-increasing number of evacuees and their complex needs. Calling for an urgent need to improve the structural, spatial, and living experiences of its users, this paper recommends learning from and adopting international AI-driven practices and smart elements in evacuation centers to improve the already dire situation. While the direct use of AI in evacuation centers is beyond the scope of this paper, the evidence presented supports its potential in addressing deficiencies. This endorses developing evidence-based policies that take advantage of AI and smart technologies, investing in capacity building for engineers and architects, and encouraging private sector partnerships to attain sustainable cities and communities.

Key Words: retrofitting with AI; smart technology; disaster mitigation; evacuation center; sustainable communities

1. INTRODUCTION

The Philippines, identified as the highest disaster risk country in the world by the World Risk Report (2024) (Paz, 2021), faces an annual onslaught of approximately twenty typhoons, leading to an increasing occurrence of flash floods and other hazards (Santos, 2021). In response to these recurring natural disasters, evacuation centers serve as the fastest source of refuge for affected populations. The Philippines has 28,083 recorded evacuation centers, 63% of these being educational institutions such as universities, public secondary schools, a majority of elementary schools, and daycare centers. The remaining facilities are multipurpose centers, basketball courts, churches, municipal halls, and covered courts (Lacerna, S.A., 2023).

Despite its multifunctionality, the condition of many public school buildings is deteriorating. According to the 2019 National School Building Inventory (Back to Basics, 2023), the Philippines has 15,334 school buildings deemed for condemnation, 13,174 buildings condemned or slated for demolition and 28,508 buildings for replacement (PIDS, 2021). A notable portion of these buildings include 100-year-old heritage structures known as the Gabaldon school, constructed between 1907 and 1915 (Lopez, 2019). Over time, these buildings have naturally degraded with constant use and are classified as nonconforming due to new building regulations. When schools are repurposed as evacuation centers, their function, occupancy loads, and other inherent architectural, utility, and structural properties are no longer suitable. All these make schools more susceptible to damage(Okada, 2021). Additionally, there is an observable, troubling trend in the Philippine rainfall intensity and frequency that floods are becoming more severe each year, with stormwater remaining undrained for more days, even after heavy rainfall, due to low-capacity drainage systems clogged with garbage. This results in buildings being waterlogged for extended periods. This situation is further exacerbated as many disaster victims stay in evacuation centers longer than initially intended, causing class disruptions, and leaving facilities dirty (Lacerna, 2023; Cinco et. al., 2014).

Disaster preparedness in the Philippines is at a critical juncture, characterized by institutional reforms and evolving strategies to mitigate the impacts of natural and manmade hazards. Typhoon Ondoy in 2010 showed the unpreparedness of the Philippines in handling disasters, which later prompted the creation of Republic Act 10121, establishing the National Risk Reduction and Management Council (NDRRMC) and a governing body comprised of disaster management teams from other government offices. This initiative aimed to address longstanding issues such as insufficient local implementation, inter-agency coordination, and funding constraints (Adam, 2021; Pacific Disaster Center, 2021). Although these reforms were in place, there were still gaps in the management and functionality, in the location and assignment of evacuation centers, as evidenced during subsequent disasters.

The devastation brought by Typhoon Haiyan in 2013 exposed the spatial inadequacies of evacuation centers. A rapid health assessment revealed that 70% of the twenty assessed centers were schools hosting anywhere between 15 to 5000 evacuees. Overcrowding was rampant and critical needs were unmet – none of these centers had officially assigned managers, standby medical teams, or proper garbage collection systems. Only four centers met the World Health Organization standard for toilet facilities, and only fourteen provided on-site vaccination for communicable diseases (Ramos, R.A. et al., 2015). Structural weaknesses were also evident, as many evacuation centers suffered damage during the typhoon (Pacific Disaster Center, 2021). Similar challenges persisted years later, as seen during Typhoon Carina in 2024. In Marikina's evacuation center, which had a capacity for 5,000 people compared to affected residents of 160,000, evacuees reported issues such as insufficient food, overcrowding, and unsanitary toilet facilities, and poor ventilation. With many displaced residents, they were forced to seek shelter in schools that were also prone to flooding (Santos & Casucian, 2024). Philippine News Agency (PNA, 2022) reported that in Western Visayas, the Department of Education Region 6's Rapid Assessment and Damages Report (RADAR) identified 380 classrooms that were damaged, with 397 more partially damaged when super typhoon Odette ravaged the country in December 2021(MENA, 2022). RADAR also reported damaged schools - seven in Ilocos and eleven in Central Luzon, eight in Cordillera Administrative Region, and nine in Cagayan Valley, due to a magnitude seven earthquake that hit northern Luzon in 2021 (PNA, 2022).

Retrofitting old buildings has emerged as a vital strategy to address these recurring challenges and enhance disaster preparedness in the Philippines. Local government units (LGUs) have increasingly recognized the importance of building retrofitting as part of a broader resilience framework, but there is no evidence of acknowledging and integrating AI and smart technologies into these systems.

Building retrofitting, AI, and smart technology integration in the evacuation center is the new nexus of resiliency. It entails modifications made to existing structures to reduce disaster exposure and increase resilience. It addresses climate change mitigation through its sustainable features (Wilkinson & Sayce, 2024) – reflective, robust, redundant, resourceful, inclusive, flexible, and integrated (Authors Rockefeller Foundation, 2022). These buildings incorporate lessons from past challenges, are designed to withstand both manmade and natural disasters (Korea Seed Industry News, 2024), utilize local, recyclable, affordable, innovative materials, and offer utility to all users. They also feature multipurpose functionality for both normal and unforeseen circumstances, achieving a harmonious balance of aesthetics, practicality, and durability.

There are four main categories of building retrofits: safety, functional/architectural, energy, and structural. Safety retrofits focus on fire protection systems by enhancing vertical and horizontal compartmentalization, integrating fire-resistant walls, sprinkler systems, fire alarms, and implementing passive fire protection measures. Functional and architectural retrofits address changes such as adding or reorganizing spaces, improving accessibility and inclusivity, incorporating technology, and integrating water conservation systems. Energy retrofits' purpose is to insulate and control the heat transfer resulting in optimized energy efficiency within the building envelope, upgrading windows into heat regulating materials that still maximize the passage of natural light, implementing natural and artificial lighting solutions, capturing renewable energy sources for electrification, improving the efficiency of HVAC systems, and employing passive design strategies. Structural retrofits are introduced into the existing building to enhance the strength of building foundations against seismic activity, floods, human-induced disasters, and changes in the load-bearing capacities. Through comprehensive retrofitting approaches, buildings can effectively combine resilience, sustainability, and adaptability to meet the demand of an increasingly disaster-prone era.

Smart buildings, also known as intelligent, automated, digitized (Al Dakheel et. al, 2020), are sensitive buildings that are reactive and interactive to conditions that lead to the overall comfort, safety, and productivity of building occupants. According to Valle (2022), smart buildings are resilient, high-performance, zero-carbon, intelligent, net-zero energy, connected, positive energy, green buildings, passive houses, sustainable, and living buildings. Smart buildings work through automation to have full control and management of a building or its systems. To automate it uses technologies such as Artificial Intelligence and Machine Learning, Virtual and Augmented Reality, Internet of Things (IoT), Artificial Reality, Building Information Modelling (BIM), Building Automation, Drones, and many more (Service Channel.com, 2024). These buildings operate using the internet to link multiple devices that analyze the existing conditions of the building, e.g., thermal, ventilation, natural or artificial light, acoustics, number of building or room occupants, traffic patterns that exchange information and change the condition to adapt to the occupants' needs. Building Information Modelling involves outputs from architects and allied professionals that unify the different information gathered to create well-integrated building systems, during the planning stage, up to its construction period. Augmented reality combines real elements such as an actual streetscape, real buildings, and maps using mobile phones and cameras. Artificial Reality is live and layered with scenes that are computer-generated, to support other technologies. Drones take aerial views or inside the building to see movement of occupants, intruders acting as the eye of the space, seeing challenging spots from far and near. When these tools are integrated into evacuation centers, evacuees are able to communicate with others regardless of time, distance, and climatic conditions; they imporve the indoor climate depending on the population and outdoor conditions, making the evacuation center comfortable and safe. In smart evacuation centers, the building conditions, resources, and occupant management become easier.

Shown in Figure 1 is the Sendai Framework model for disaster risk reduction to critical infrastructure and disruption of basic services, including health and educational facilities (MENA, 2021). It has four priorities: 1) know and understand disaster risk, 2) enhance disaster management, 3) invest in disaster risk reduction and resilience, and 4) enhance disaster preparedness and response by "building back better" in the recovery, rehabilitation, and construction (UNDRR, 2024). Structural retrofitting with AI monitoring tools was identified in previous Japanese research and product development. This was tabulated to know which type of retrofitting is the most used for similar buildings – public schools, evacuation centers, and dwellings.

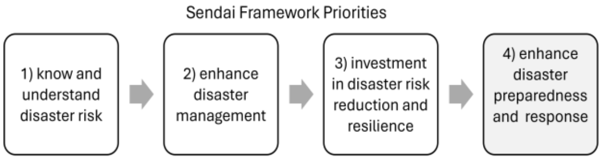

Figure 1. Sendai Framework section 4: Enhance disaster preparedness and response through Build Back Better.

2. METHODOLOGY

A mixed methods approach of mapping analysis, field survey of 30 public school buildings and designated evacuation centers, and evacuees' interviews was done. The field survey results were compared with standard designs and successful retrofitting cases from Japan, AI, and smart technology applications with similar contexts, through bibliometric data.

3. RESULTS AND DISCUSSION

In Figure 2, the map analysis of public school buildings, flood hazard, and storm surge from the Department of Science and Technology's real-time hazard channel, Hazard Hunter, showed that these buildings (red circles) are located in flood-prone areas (dark purple) and storm surge areas (light purple), evidence to improve the urban disaster planning.

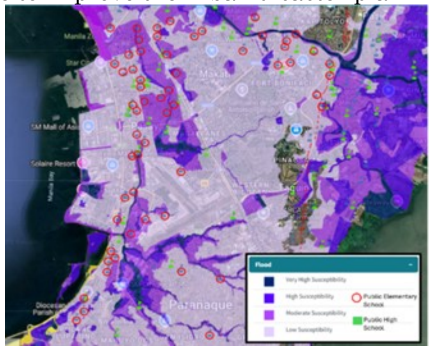

Figure 2. Flood Hazard and Public School Buildings in Manila (source: HazardHunter)

Bibliometric data in Table 1 shows works on Japan's retrofitting methods in old buildings, including schools and high occupancy spaces, to enhance the structural integrity. The structural performance is monitored using AI that provides a warning when a disaster damages the building.

Table 1. Structural Retrofit with AI Monitoring

Author Publication	Endured Disaster	Building Feature	Retrofit with AI
Yamamoto et al. (2005)	1978	Built 1970, 64m high-rise, mixed-use	Energy absorption braking with low yield point steel
Yamamoto et al. (2005)	1995	Built 1920, 2-storey university chapel	Base isolation
Yamamoto et al. (2005)	1995	Int'l. Library of Children's Literature	Base isolation
Yamamoto et al (2005)	1995	327 high-rise buildings	Base isolation
Takeda, et al (2013)	2011	Municipal Junior High School	External precast concrete frames
Takeda et al. (2013)	2011	Miyagi Prefecture High School	External cast-in-place concrete shear walls
Fujino et al. (2019)	2021	130 high-rise buildings	Vibration controlled
Nakamura, Okada (2019)	2011	Built 1958 National Museum of Western Art	Seismic isolation
Kurosawa et al (2019)	2024	Residential, commercial	Precast prestressed
Okada (2021)	2024	85,000 schools retrofitted, 65% still exist	Reinforced concrete walls, steel-braced frames, steel

			plates/carbon fiber sheets jacket columns
Okada (2021)	2024	Built 1914, Tokyo Railway Station	Base isolation

Interviews and design comparison from the Department of Public Works and Highways (DPWH) and WHO, with the actual condition of evacuation centers, reveal spatial, functional, and experiential deficiencies. The building's emergency and temporary capacity is inadequate. DPWH standard evacuation centers have a floor area of 560sqm in Option 1 and 982 sqm in Option 2. Following a 1.5sqm per person, Option 1 shall have an occupancy of 373 evacuees, and Option 2 shall have 655 evacuees. Overcrowding is evident because the size is less than 1-1.5 square meters per person, and the site capacity is less than 3.5 square meters per person. Considering toilets and hygiene needs, not all centers followed the WHO standard of twenty people per latrine. In Option 1, there is no permanent toilet, and in Option 2, there are three water closets for males and females, which should serve only 120 people. Although public schools limit the use to the ground floor, they have other spaces, including a small kitchen. There is no well-identified waste segregation and disposal area, and insufficient ramps and handrails. Windows and openings do not maximize natural light and ventilation, and there is a low number of safety devices and features.

The bibliometric data in Table 2. Indicates safety, functional/architectural, and energy retrofit using AI and smart technology. Samples of research from indexed sources show that there is a growing curiosity and application of AI and smart technology in buildings that are replicable.

Table 2. Safety, functional/architectural, and energy retrofit using AI and smart technology

Author Publication	Building Feature	AI and Smart Technology
Abdel-Razek et al. (2022)	Energy efficiency	K-nearest neighbors (KNN), machine learning
Zhao, et al. et al. (2023)	Simulation of emergency evacuation	Available safe egress time (ASET) required safe egress time RSET model
Elnabawi et al. (2025)	Thermal Comfort	Artificial Neural Networks (ANN)
Li et al. (2025)	Thermal, visual, and olfactory sub-environment	AR, VR, LiDAR
Himeur, et al (2025)	Building automation and management	Big data analytics tools
Velasco et al. (2023)	Air cooling and filtering systems	Thermal sensors
Jiang et al. (2025)	Real-time air quality change	BIM and digital twins
Luo (2022)	Energy efficiency, thermal comfort	Internet of Things
Chen et al. (2024)	Triple glazing for thermal comfort	Reactive building material

Although this research did not involve experiments on the use of AI and smart technologies in evacuation centers, the evacuee experiences, comparative analysis of buildings and a bibliometric review of technological precedents resulted in a better understanding of the conditions and formed an argument that modern solutions are available.

4. CONCLUSIONS

There is an urgent need to improve evacuation centers, not only in terms of structural safety but also in terms of fire safety, architectural, and energy needs. Drawing from the literature, observations, and interviews, the use of AI and smart technologies is a tool to achieve the evacuation center standards. The evidence presented affirms their potential to address deficiencies where human intervention might no longer be enough. As a contribution to SDG 11: Sustainable Cities, this paper endorses developing evidence-based policies that take advantage of AI and smart technologies, investing in capacity building for professionals in the built environment, and encouraging private sector partnerships to formulate modern, practical, and sustainable solutions grounded in the Philippine context.

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