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FIRE-RESPONSIVE ARCHITECTURE: A FRAMEWORK FOR THE DESIGN OF MULTIFUNCTIONAL EXHIBITION CENTRES IN JOS, PLATEAU STATE, NIGERIA

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ABSTRACT

Exhibition centres and trade fair facilities occupy a uniquely demanding position within the public assembly building typology. Their combination of high occupant densities, large open-plan spaces, variable combustible loads, and the frequent presence of users unfamiliar with their surroundings creates fire risk conditions of exceptional complexity. In developing economies such as Nigeria where fire safety governance is often inconsistently enforced, permanent exhibition infrastructure remains scarce, emergency service capacity is limited, and utility infrastructure is unreliable; these challenges are significantly compounded. This paper advances the concept of fire-responsive architecture: an approach in which fire safety principles are embedded as generative design drivers from the earliest stages of spatial planning, rather than applied retrospectively as technical overlays. Drawing on a systematic review of fire safety literature and a structured comparative analysis of three trade fair facilities in Nigeria, the United States, and Germany, the paper derives a five-dimensional framework addressing: site planning for fire safety; passive structural and spatial fire protection; active suppression and detection systems; smoke ventilation and control; and emergency egress. The framework is contextualised against the conditions of West African developing economy cities using Jos, Plateau State, Nigeria as an illustrative reference context and demonstrates that fire-responsive design is achievable through conventional architectural and engineering decision-making. The framework offers a replicable methodology for architects and built environment practitioners working on large public assembly facilities across sub-Saharan Africa and comparable developing-world contexts.

Keywords: Fire-responsive architecture; exhibition centre design; trade fair facilities; passive fire protection; public assembly buildings

1. INTRODUCTION

Trade fairs and exhibition centres occupy a unique and increasingly important position in the economic landscape of developing nations. As physical platforms for industrial promotion, foreign investment attraction, technology transfer, and intra-regional commerce, they enable face-to-face commercial engagement that digital channels cannot fully replicate. According to the United Nations Conference on Trade and Development, the implementation of the African Continental Free Trade Area uniting 55 countries with a combined population of 1.3 billion and a GDP of USD 3.4 trillion has strengthened demand for physical trade facilitation infrastructure across the continent (UNCTAD, 2024). Yet permanent purpose-built exhibition infrastructure remains scarce across much of sub-Saharan Africa, with many cities continuing to rely on temporary or makeshift venues that are inadequately planned and poorly serviced (Shore Africa, 2025). Cities such as Jos, Plateau State, Nigeria with a documented history of trade fair activity and a commercially active chamber of commerce exemplify this deficit, having never established a permanent exhibition facility despite decades of periodic trade fair activity (PLACCIMA, 2016; Plateau State Government, 2024). This infrastructural gap raises urgent questions not only about economic investment and urban planning, but about building safety. Exhibition centres and trade fair facilities present a fire risk profile that is among the most demanding within the public assembly building typology. They combine high occupant densities, large open-plan spaces, variable and often substantial combustible loads introduced by exhibitors, irregular occupancy patterns, and the consistent presence of visitors unfamiliar with the building's layout and emergency provisions (Kodur *et al.,* 2020; Kizilkaya Oksuz *et al.,* 2023). Assembly occupancies experience the highest occupant densities of any building type, placing exceptional importance on means of egress, structural fire resistance, suppression systems, and reliable occupant notification (Nimlyat *et al.,* 2017). These risk conditions are significantly compounded in developing economies where construction quality is variable, building services are unreliable, and emergency response capacity is constrained (Martins *et al.,* 2024).

In Nigeria, the consequences of inadequate fire safety provision in public buildings are severe and worsening. Statistical analysis of fire incidents in public buildings has consistently identified electrical faults, substandard materials, and poor building design as primary causal factors (Adekunle *et al.,* 2018; Oloke *et al.,* 2022). Despite the existence of formal regulatory frameworks, fire safety management in Nigerian public buildings remains critically inadequate, with the majority of assessed buildings lacking functional suppression systems, trained emergency personnel, and operational fire safety management plans (Alao *et al.,* 2021). A review of building design practice and fire codes in Nigeria identifies three interrelated systemic issues: the absence of adequate legislative backing for fire safety standards, insufficient technical capacity among building professionals, and a near-total absence of post-construction inspection and enforcement (David et al., 2019). Between 2015 and 2022, fire incidents cost Nigeria over ₦3.19 trillion in property losses, with ₦46.1 billion lost in 2022 alone (Neusroom, 2023). Over 266 fire outbreaks were recorded in the first half of 2024 alone, demonstrating a marked and continuing increase in the frequency and scale of fire catastrophes in Nigeria's built environment (Sholanke *et al.,* 2025).

The conventional response; specifying minimum regulatory standards evaluated at the point of approval has well-documented limitations. Fire design is frequently carried out primarily to obtain regulatory approval rather than to achieve genuine occupant safety, and fire safety evaluation is rarely integrated into the iterative design process (Kodur *et al.,* 2020; Maluk *et al.,* 2017). A building's spatial layout; its overall form, internal partitions, and room configuration significantly influences the spread of smoke and heat in ways that prescriptive compliance does not adequately address (Park *et al.,* 2013; Ulpan and Kazkeyev, 2021). In contexts where enforcement is unreliable, a compliance-centred paradigm is structurally insufficient: a building that satisfies minimum requirements on paper but is spatially poorly organised and inadequately constructed provides little genuine safety to its occupants (David *et al.,* 2019; Sholanke *et al.,* 2025).

This paper proposes fire-responsive architecture: an approach in which fire safety is treated as a generative design principle embedded in spatial organisation, structural selection, material specification, and site planning from the earliest stages of the design process, rather than applied retrospectively as a technical overlay. Drawing on a critical review of fire safety literature and a structured comparative analysis of three trade fair facilities in Kaduna (Nigeria), Utah (USA), and Leipzig (Germany), the paper develops a five-dimensional fire-responsive design framework applicable to multifunctional exhibition buildings in developing economy contexts. The conditions of Jos, Plateau State, Nigeria characterised by weak regulatory enforcement, constrained emergency service infrastructure, and seasonal fire risk variation are used as an illustrative contextual reference throughout.

2. LITERATURE REVIEW

2.1 The Fire Risk Profile of Exhibition and Trade Fair Buildings

Large public assembly buildings present fire safety challenges that are qualitatively different from conventional occupancies such as offices or residential buildings. Exhibition centres and trade fair facilities are particularly demanding: a trade fair hall at peak occupancy may simultaneously contain thousands of visitors, complex temporary display structures, electrical installations of varying quality, flammable or combustible exhibit materials, and operational staff who may be the only persons with knowledge of the building's layout. Unlike a permanent office or retail building, the internal configuration of an exhibition centre changes fundamentally between events: partitions are erected and dismantled, fuel loads which are substantial shift from exhibitor category to exhibitor category, and the spatial logic that might orient a visitor during one event may be entirely absent during the next (Alfalah *et al.,* 2023; KADCCIMA, 2025). These characteristics combine to create a highly variable risk environment in which the fire hazard cannot be fully characterised by the building's physical fabric alone (Kodur *et al.,* 2020). Most fire casualties result not from direct flame contact but from smoke inhalation and toxic gas exposure, conditions significantly worsened in large open-plan spaces where smoke can accumulate rapidly across a wide area (Lei *et al.,* 2023). The design and organisation of a building are closely related to the ease of evacuation in the event of a hazard, the degree of fire spread, and the effectiveness of the fire protection system, with spatial layout significantly influencing the design of smoke control systems, the placement of detection devices, and the configuration of escape stairways (Nimlyat *et al.,* 2017). An assessment of multi-functional facilities across Nigerian and international trade fair complexes found that fire safety infrastructure including fire prevention posts, emergency firefighting systems, and fire access roads was consistently absent or inadequate at Nigerian facilities, including the Kaduna International Trade Fair and Investment Centre (Kodei *et al.,* 2023).

2.2 The Fire Safety Framework: Objectives, Principles, and Tactics

The International Fire Safety Standards Coalition (IFSS, 2020) identifies five core principles applicable across building types, climatic contexts, and regulatory environments: prevention, detection and communication, occupant protection, containment, and extinguishment. These principles are interdependent: the failure of any one increases the burden on the others, and effective fire safety design seeks to address all five in an integrated manner. Prevention encompasses strategies to reduce the probability of ignition through heat source control, fuel limitation, and careful selection of building materials and contents. Detection and communication ensures that a fire, once initiated, is rapidly identified and that occupants and emergency services are promptly alerted. Occupant protection focuses on providing sufficient time and unobstructed pathways for all building users to reach safety. Containment limits the spread of fire and its products of combustion to the smallest possible area through compartmentation, smoke control, fixed firefighting systems, structural integrity, and controlling the combustibility and smoke performance of materials used (IFSS, 2020). Extinguishment involves the active suppression of fire through automatic systems and manual firefighting operations. Systematic fire safety assessment models such as the analytic hierarchy process model proposed by Alfalah et al. (2023) reflect a growing recognition that fire safety performance is multidimensional and cannot be adequately captured by any single measure. Current fire protection measures do not adequately account for all contemporary fire hazard issues; an integrated framework must address fire protection features, regulation and enforcement, consumer awareness, and technology advancement in a coordinated manner (Kodur *et al.,* 2020; David *et al.,* 2019; Alao *et al.,* 2021).

2.3 Passive Fire Safety Strategies in Large Buildings

Passive fire protection encompasses those elements of building design and construction that resist or retard the spread of fire and smoke without requiring mechanical activation or human intervention. These include structural fire-resistant materials, fire-rated wall and floor assemblies, compartmentation barriers, fire doors and shutters, firestopping at service penetrations, and intumescent coatings on structural members (Martins *et al.,* 2024). Passive systems are more reliable over the building lifecycle than active systems because they do not depend on mechanical or electrical components at the moment of a fire event, a particularly important consideration in developing-economy contexts where building services maintenance is unreliable (Oloke *et al.,* 2022). Compartmentation, the subdivision of a building into discrete fire-resistant zones so that a fire starting in any one zone is contained within it for a period sufficient to allow occupant evacuation and fire brigade intervention is the most important passive strategy for large-footprint buildings (NFPA, 2024). In exhibition buildings, grouped hall configurations in which the facility is composed of several discrete, individually fire-rated halls represent the most widely adopted architectural response to this challenge (Ulpan and Kazkeyev, 2021). Steel, the dominant structural material in large-span exhibition halls, can lose up to 50% of its yield strength at approximately 550°C, leading to structural failure within minutes of fire exposure; protection through concrete encasement, intumescent coatings, or mineral wool wraps is essential (Martins *et al.,* 2024). In the Nigerian context, empirical testing of building materials has found significant variation in fire performance indices across commonly used construction materials, with direct implications for the specification of interior finishes and structural elements in public assembly buildings (Omofunmi and Abiwo, 2019).

2.4 Active Fire Safety Systems

Active fire protection encompasses those systems that detect fire conditions and respond through mechanical, electrical, or human action. Automatic sprinkler systems remain the most effective and widely specified active fire suppression technology for large public assembly buildings, providing simultaneous fire suppression, occupant warning, and structural protection (Kodur *et al.,* 2020). The effectiveness of sprinkler systems is contingent on adequate water supply pressure, appropriate head spacing, and integration with the building's alarm and detection systems. This dependency on mains water supply reliability is a significant consideration in developing-economy contexts where supply interruptions are common (Oloke *et al.,* 2022). Two-stage alarm configurations in which an initial alert is communicated to staff and a second stage triggers full occupant evacuation are particularly appropriate for large public assembly buildings where the simultaneous evacuation of thousands requires coordinated management to avoid panic and congestion at exits (Hassanain *et al.,* 2022). A study of fire safety management strategy in Nigerian public buildings found that detection and alarm systems were consistently absent or inadequately maintained, reinforcing the importance of specifying systems with built-in redundancy appropriate to contexts of weak institutional oversight (Alao *et al.,* 2021).

2.5 Smoke Ventilation and Control

Smoke is the primary cause of death in building fires, and its management is a central preoccupation of fire safety engineering in large-volume spaces. In single-storey exhibition halls, natural smoke venting through roof openings calibrated at a minimum of 2.5% to 5% of the floor area is the most common and cost-effective strategy, relying on the buoyancy of hot gases to drive smoke upward while cooler replacement air enters at low level. With increased natural vent areas, the clearance height of the smoke layer is raised so that occupants are exposed to lower smoke radiation and toxicity (Chow *et al.,* 2022). Natural venting is generally preferred in developing-economy contexts where power supply continuity cannot be assumed. In buildings incorporating atria, smoke management presents significantly greater complexity: atria can facilitate the rapid vertical migration of smoke throughout a building if not adequately controlled, and smoke control ventilation systems play a significant role in keeping evacuation routes available for people (Brzezinska and Bryant, 2022). Mechanical exhaust systems, in which fans actively extract smoke from the upper zone of the atrium while makeup air is supplied at low level, are most commonly specified for complex atrium configurations (Lei *et al.,* 2023).

2.6 Means of Escape

Effective egress design requires that exit routes are sufficient in number, width, and proximity to ensure that all occupants can reach a place of safety within the available safe egress time (ASET), defined as the period between fire ignition and the onset of untenable conditions in the occupied zone (Kizilkaya Oksuz *et al.,* 2023). The key design variables for egress in exhibition buildings include: the number and width of exits from each hall or zone, calculated on the basis of occupant load; travel distances from the furthest point within the hall to the nearest protected exit route; the protection of escape routes from smoke ingress; the provision of emergency lighting and directional signage; and the provision of alternative escape routes (Hassanain *et al.,* 2022). For buildings with large open-plan exhibition halls, smoke can accumulate across a wide area simultaneously, making the integration of smoke venting with escape route design a particularly important design coordination task. Computational simulation of alternative spatial layouts has confirmed that spatial decisions including the number and configuration of enclosed spaces, the width and direction of door openings, and the distribution of occupants significantly alter individual fire risk outcomes and evacuation performance (Ulpan and Kazkeyev, 2021).

2.7 Fire-Responsive Architecture: Positioning the Concept

The foregoing review makes clear that fire safety in large public assembly buildings is not a single-system problem. It is a multi-dimensional design challenge that engages spatial organisation, structural engineering, materials science, services engineering, and operational management simultaneously. The integration of competent fire safety engineering principles from the onset of the design process has significant potential to deliver a better building, since it is based on principles of optimisation where the best solution is found through consideration of all relevant design variables simultaneously rather than sequentially (Mostafa *et al.,* 2024). Maluk *et al.* (2017) observe that fire safety is currently perceived in design practice as an additional constraint rather than a design parameter, and argue that integrating fire safety into the iterative design process is crucial to producing buildings that are genuinely rather than nominally safe. Park *et al.* (2013) demonstrate that the spatial layout of a building significantly influences the movement of smoke and heat in ways that prescriptive compliance measures do not capture. In Nigeria specifically, a review of building design practice and fire codes identifies the failure to integrate fire safety into the design process at the planning stage as one of the three primary structural drivers of inadequate fire safety outcomes in public buildings (David et al., 2019). Fire-responsive architecture treats the five common principles of fire safety (IFSS, 2020) as design generators with spatial, structural, and material implications, engaged from the earliest stages of schematic design.

3. MATERIALS AND METHODS

This paper employs a qualitative, secondary-data research methodology structured in three sequential and interrelated phases: systematic literature review, comparative case study analysis, and contextual framework development. The choice of a qualitative approach reflects the paper's purpose to develop a transferable conceptual framework through evidence synthesis and comparative analysis rather than to test a hypothesis through primary data collection or quantitative measurement. In the built environment disciplines, qualitative methodologies including systematic literature review, case study analysis, and framework development are well established as appropriate and rigorous approaches to design-oriented research problems where the goal is the generation of transferable knowledge rather than statistically generalisable findings (Aksamija, 2020).

3.1 Phase One: Systematic Literature Review

Sources were identified through systematic database searches of Scopus, Web of Science, and Google Scholar using the search terms 'fire safety,' 'public assembly buildings,' 'exhibition centres,' 'trade fair facilities,' 'passive fire protection,' 'active fire suppression,' 'smoke ventilation,' 'means of escape,' 'fire-responsive design,' 'developing economies,' and 'Nigeria.' Priority was given to peer-reviewed journal articles published between 2015 and 2025, supplemented by internationally recognised fire safety standards including NFPA 101 (2024), NFPA 13 (2024), and the International Fire Safety Standards Coalition Common Principles (IFSS, 2020). Sources were excluded on the basis of irrelevance, non-peer-reviewed origin where peer-reviewed equivalents were available, and inability to verify accessibility through a public or institutional repository.

3.2 Phase Two: Comparative Case Study Analysis

Three trade fair and exhibition centre facilities were selected through purposive sampling; the intentional selection of specific cases based on their relevance to the research question and capacity to yield rich, information-dense data (Campbell *et al.,* 2020) to represent a deliberate spectrum from local to international context: the Kaduna International Trade Fair and Investment Centre (Nigeria), the Mountain America Exposition Center (Utah, USA), and the New Trade Fair Leipzig (Germany). Each case was analysed against a common five-criterion framework corresponding to the IFSS (2020) five fire safety principles. Data were drawn mainly from publicly accessible documentary sources consistent with established secondary case study analysis practice in the built environment (Ebneyamini and Sadeghi Moghadam, 2018; Yin, 2018).

3.3 Phase Three: Contextual Framework Development and Limitations

The contextual conditions presented in Section 4.6 were developed from published literature, government documentation, and verified meteorological data. Jos, Plateau State, Nigeria is used as an illustrative reference context rather than a design object, representative of a class of developing-economy urban conditions prevalent across West Africa. Three methodological limitations are acknowledged: the case study analysis relied more on documentary rather than primary fieldwork evidence; the framework has not been validated through computational fire modelling such as Computational Fluid Dynamics simulation (Zeng and Huang, 2025); and the climatic calibration of some framework provisions is based on the Jos highland climate zone data and would require recalibration for application in other West African climatic zones.

4. RESULTS AND DISCUSSION

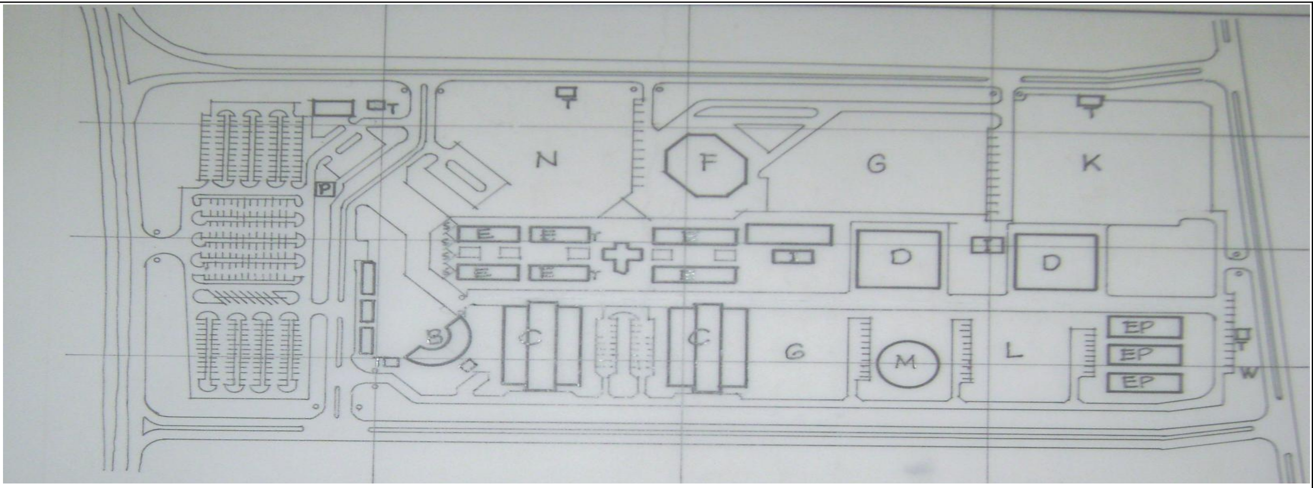
4.1 Analytical Framework

The comparative analysis applies the five-principle fire safety framework; prevention, detection and communication, occupant protection, containment, and extinguishment as a common evaluative lens across the three selected case studies. Each case is assessed across five dimensions: spatial organisation and planning layout; structural system and materials; fire safety provisions; circulation and emergency egress; and transferable design lessons. The foreign case study data for the were drawn exclusively from publicly accessible documentary sources consistent with the secondary case study methodology described in Section 3.2 while the local case study data included fieldwork.

4.2 Case Study 1: Kaduna International Trade Fair and Investment Centre, Nigeria

The Kaduna International Trade Fair and Investment Centre, located at Kilometre 4 of the Kaduna-Zaria Expressway at Rigachikun, is the most significant permanent trade fair facility in Nigeria and one of the few purpose-built exhibition complexes in West Africa operating at a recognised international standard. Kodei *et al.* (2023), notes that the centre was designed and supervised by Archcon Nigeria Ltd and construction was completed in 1998, with the client being the Federal Government of Nigeria through the Petroleum Trust Fund. Organised and staged by the Kaduna Chamber of Commerce, Industry, Mines and Agriculture (KADCCIMA), the fair is described as the largest commercial event in Nigeria and in Africa, with participants drawn from across the globe including India, Egypt, Bangladesh, Pakistan, Germany, Iran, and several West and Central African nations (NEPC, 2019). The Kaduna International Trade Fair has maintained continuous operational status, with the 46th edition held in February 2025 and the 47th edition held in February 2026, confirming the facility's sustained relevance as West Africa's largest commercial event platform (KADCCIMA, 2025; Blueprint Newspapers, 2025).

The centre is built with a decentralised, open-air pavilion layout connected by wide, designated walkways. It adopts a linear exhibition park model, with individual buildings including exhibition halls, a grand stand and festival ground, a conference centre, permanent shopping arcades, restaurants, and an amusement park arranged as discrete structures along a pedestrian concourse. Exhibition halls are single-storey steel portal frame structures with aluminium-clad walls and roofing sheets, a construction typology characteristic of large-span Nigerian commercial buildings (Oloke *et al.,* 2022). These high-clearance pavilion buildings feature high ceilings and overhanging eaves designed for maximum ventilation, minimising the risk of rapid smoke build-up during an indoor emergency. The fire safety strategy relies primarily on building separation across the site as a substitute for internal compartmentation; a planning-level approach that mitigates cross-building fire spread but leaves individual buildings exposed to internal fire risk without documented comprehensive active suppression (Martins *et al.,* 2024; Alfalah *et al.,* 2023). The Kaduna International Trade Fair's operational regulations require that free access roads be maintained at all times for fire control equipment and water towers, and confirm that a fire service is provided within the fair complex for emergency response representing a significant passive and active fire safety provision at the site level (KADCCIMA, 2025). The Kaduna case demonstrates that building separation at the site planning level is a viable and cost-effective passive fire strategy for trade fair complexes in resource-constrained contexts, but reveals the limitations of a planning-level-only approach.



A - Gates & Monument	F - Conference Centre	M - American Dome	SP - Security Post
B - Festival Ground	G - Green Areas	N - Amusement Park	T - Toilet
C - Exhibition Hall	I - State Pavillions	P - Plaque	TB- Ticket Boot
D - Small Scale Exhibition	J - Technical & Security	Q - Parking Spaces	W - Water Reservoir
E - Shopping Arcades	K - Open Exhibition Area	R - Restaurants	
EP - Expo Halls	L - Industrial Exhibition	S - Exit and Entry Point	

Plate 1A: Site Layout Plan of the Kaduna International Trade Fair and Investment Centre showing the linear exhibition park arrangement and separated building clusters. Source: Traced from (KADCCIMA, 2025).


C - Exhibition Halls


D - Small Scale Exhibition


E - Shopping Arcades


EP - Expo Halls


F - Conference Centre


M - American Dome

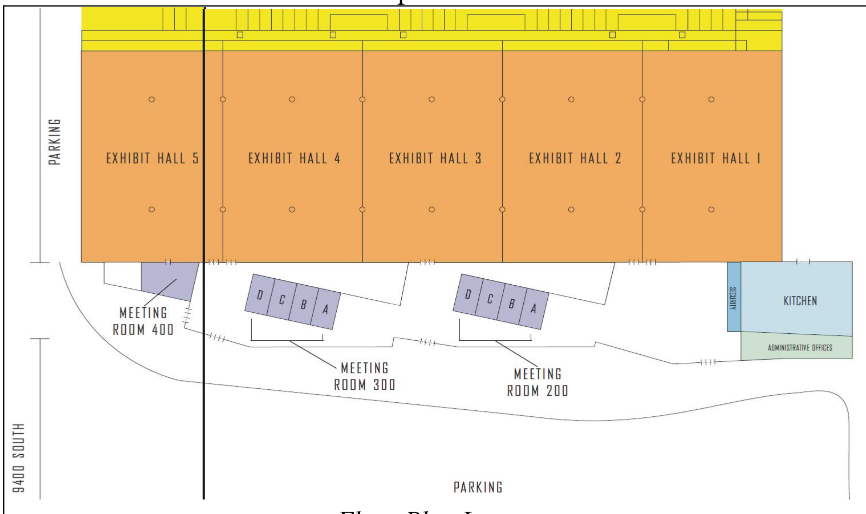
Plate 1B: Facilities at Kaduna Trade Fair and Investment Center. Source: Fieldwork (2025).

4.3 Case Study 2: Mountain America Exposition Center, Utah, USA

The Mountain America Exposition Center, located at Sandy, Utah, was opened in November 2000 at a cost of USD 46 million to Salt Lake County. It offers 22,575 square metres of contiguous exhibit hall space divisible into five halls with 9-metre ceilings, 1,394 square metres of meeting room space divisible into nine separate rooms, 30 loading docks, and 1,700 on-site parking spaces (Mountain America Exposition Center, 2024). The centre has achieved Global Biorisk Advisory Council

(GBAC) STAR accreditation, reflecting its commitment to comprehensive safety management.

The building is designed as a single unified complex with a linear circulation spine giving access to five divisible exhibition halls, meeting rooms, loading docks, administrative offices, and food service concessions. Each hall is provided with its own concession stand, restrooms, and loading access, enabling simultaneous, independent events within the same building without cross-interference between occupancies. The NFPA 101 Life Safety Code and the International Fire and Building Code are the established standards for review of occupancies and events in the facility, with all drapes, curtains, table coverings, skirts, carpet, and any materials used in exhibits required to be flame retardant, and all fire safety devices; hose cabinets, extinguishers, sprinklers, exit doors, emergency lighting, alarm sending stations, and strobe lights integrated throughout and must not be hidden, obstructed, or otherwise disturbed (Mountain America Exposition Center, 2024). The facility is fully protected by an automatic fire sprinkler system, with compartmentation of exhibition halls through fire-rated partition systems. The Mountain America case demonstrates that fire safety and operational flexibility are complementary, not competing, values; a single unified building can be effectively compartmented, fully sprinklered, and comprehensively equipped with active fire safety systems while simultaneously accommodating diverse simultaneous events at high occupant densities (Maluk *et al.,* 2017).



Floor Plan Layout

Exhibition Hall Interior

Plate 2A: Mountain America Exposition Center, Sandy, Utah, showing divisible hall configuration and linear circulation spine. Source: Visit Salt Lake (2024).

Exterior panoramic view

Meeting Room Interior

Plate 2B: Mountain America Exposition Center, Sandy, Utah, showing the entrance façade predominated by steel and extensive glazing spreading across the facility and one of the Meeting Rooms. Source: Visit Salt Lake (2024).

Meeting Room Concourse

Mountain Halls 1 & 2 Lobby interior.

Plate 2C: Mountain America Exposition Center, Sandy, Utah, showing the Circulation spaces
Source: Visit Salt Lake (2024).

4.4 Case Study 3: New Trade Fair Leipzig, Germany

The New Leipzig Trade Fair (Neue Messe Leipzig) is one of the most architecturally significant exhibition centres constructed in the late twentieth century, designed by von Gerkan, Marg and Partners (gmp) with the Glass Hall designed in collaboration with Ian Ritchie Architects. The exhibition and congress centre, built between 1993 and 1996, comprises 111,900 square metres of exhibition space in five buildings and a landscaped park with an additional 70,000 square metres of outdoor exhibition space. The emblematic symbol of the complex is the vaulted Glass Hall; the world's largest fully glazed structure, a steel and glass construction spanning 80 metres, 244 metres in length, and reaching 30 metres in height at its crown (Galvanizers Association, 1996).

The underlying planning concept is a linear exhibition park with five square exhibition halls arranged on either side of a central pedestrian spine. The Glass Hall serves as the central entrance and linking element, with the separation of entrance and exhibition levels enabling different events to take place simultaneously in different halls without visitors or fire moving freely between them. A ring road enables exhibition halls to be reached separately from visitor traffic. Emergency exits are incorporated into the diagonal glass-bridge connectors linking halls to the Glass Hall, with glazed lift-away doors activated by magnetically controlled equilibrium mechanisms. Exhibition halls are subdivided into 5,000-square-metre segments through sliding fire-rated partitions. Sprinkler systems, fire alarms, fire extinguishing equipment, smoke alarms, and closing devices for the doors of the halls must be accessible and visible at all times, with exhibitors required to fit at least one fire extinguisher per stand and an additional extinguisher every 200 square metres (Leipziger Messe, 2024). Mechanical ventilation enables active smoke control in the large-volume Glass Hall (Brzezinska and Bryant, 2022; Lei *et al.,* 2023). The Leipzig case demonstrates that fire safety provisions, particularly emergency egress routes can be seamlessly incorporated into primary circulation architecture without compromising aesthetic ambition, and that even the most technically challenging large-volume glazed structures can be made fire-safe through coordinated architectural and engineering design.

Plate 3A: Aerial view of the New Trade Fair Leipzig showing the linear exhibition park arrangement and the central Glass Hall spine. Source: gmp Architekten (2024).

Plate 3B: Exterior view of the Glass Hall, New Trade Fair Leipzig. Source: gmp Architekten (2024).

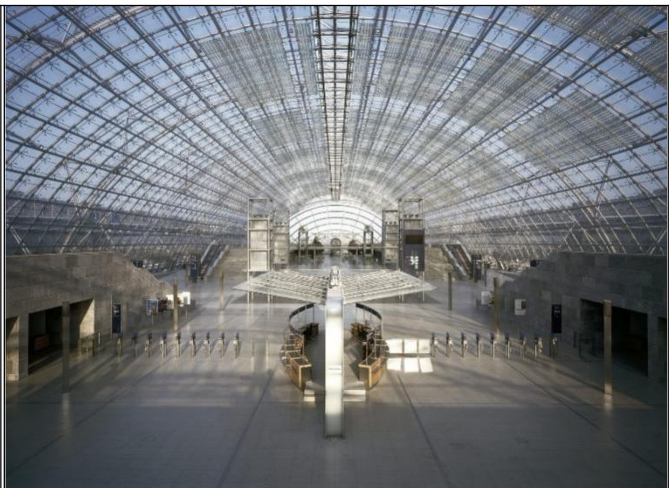


Plate 3C: Interior of the Glass Hall showing the steel and glass vault structure. Source: gmp Architekten (2024).

4.5 Comparative Synthesis and Transferable Lessons

Three transferable lessons emerge clearly from the comparative analysis. First, fire safety and spatial flexibility are compatible and mutually reinforcing design values: all three facilities demonstrate that the subdivision of large halls into smaller fire zones enhances operational versatility as well as fire containment (Kodur *et al.,* 2020). Second, the integration of fire safety provisions into primary architectural elements; circulation routes, structural systems, and building envelopes, produces better outcomes than their addition as technical afterthoughts (Maluk *et al.,* 2017; Park *et al.,* 2013). Third, design-embedded fire safety must be supported by operational management systems including exhibitor materials regulation, regular inspection, and evacuation preparedness to remain effective under variable occupancy conditions characteristic of the exhibition typology (Hassanain *et al.,* 2022). In developing-economy contexts where regulatory enforcement cannot be assumed, this finding reinforces the argument for a design-led approach in which the building's spatial and structural fabric provides the primary layer of fire safety, independently of post-construction enforcement.

Table 1: Comparative Fire Safety Provisions Across Three Case Study Facilities

Fire Safety Principle	**Kaduna, Nigeria**	**Mountain America, USA**	**Leipzig, Germany**	**Framework Implication**
Prevention	Building separation; steel and aluminium construction	Exhibitor materials regulation; NFPA 101 compliance	Subdivided halls; regulated exhibit materials; per-stand extinguisher requirement	Zone high-hazard uses to site periphery; specify non-combustible permanent building fabric
Detection & Communication	Limited documentation of active systems	Full detection, alarm, strobe lights, public address	Zoned detection; two-stage alarm; automatic door closure systems	Heat detectors in large-volume halls; two-stage alarm configuration
Occupant Protection (Escape)	Pedestrian concourse; site-level egress routes	Exit doors, emergency lighting, exit signage throughout	Emergency exits in diagonal connectors; magnetically activated glazed doors	Integrate egress routes into primary circulation; minimum four exits per hall
Containment	Spatial separation between discrete buildings	Five compartmented divisible halls; fire-rated partitions	Sliding fire partitions; mechanical ventilation; entrance/exhibition level separation	Grouped hall configuration; fire-rated compartment boundaries; atrium smoke control
Extinguishment	Limited documentation of suppression systems	Full automatic sprinkler system; hose reels; extinguishers throughout	Per-stand extinguishers; sprinkler coverage; fire brigade access ring road	Full wet-pipe sprinkler system with dedicated overhead water reservoir

4.6 Developing-Economy Contextual Conditions

4.6.1 Regulatory and Governance Deficit

A defining characteristic of the built environment in developing economy cities is the structural gap between formal regulatory frameworks and their practical implementation. Fire safety regulations are always a major challenge in developing countries due to lack of enforcing mechanisms, awareness, and resources (Murthy and Jain, 2021). In Nigeria, professionals are often constrained from efficiently applying fire safety codes due to their inaccessibility and complexity, weak law enforcement, and client affordability considerations (David *et al.,* 2019). An assessment of fire safety management strategy in Nigerian public buildings found that the majority of assessed buildings lack functional suppression systems, trained emergency personnel, and operational fire safety management plans (Alao *et al.,* 2021). A study of fire safety provisions in peri-urban residential buildings in Ibadan found a significant gap between codes prescribed and systems found in practice (Adeleke *et al.,* 2022). This regulatory and institutional deficit makes design-embedded fire safety not merely preferable but necessary: where the regulatory system cannot guarantee safety through enforcement, the building itself must be inherently fire-safe through its spatial organisation, structural specification, and material selection (Kodur *et al.,* 2020; Maluk *et al.,* 2017).

4.6.2 Emergency Service Infrastructure Constraints

Fire service response in Nigerian cities is constrained by inadequate equipment, insufficient staffing, poor road connectivity, and budgetary limitations (Silas *et al.,* 2021). Nigeria records approximately 7,000 fire incidents annually with over 1,000 casualties and assets worth USD 250 million lost to fire disasters every year (Nimlyat *et al.,* 2017). Vehicular accessibility is a major component of land use which, if absent, increases vulnerability to fire hazards, since response time to emergency calls is a function of accessibility (Jokotade *et al.,* 2026). A GIS-based network analysis of fire station service coverage in Kano Metropolis found that existing arrangements leave large portions of the urban area outside acceptable response time boundaries (Sulaiman *et al.,* 2023). These realities reinforce the case for large public assembly buildings to incorporate on-site fire response capabilities and passive provisions capable of limiting fire spread for significantly longer periods than international standards assume (Nimlyat *et al.,* 2017; Kodur *et al.,* 2020).

4.6.3 Seasonal Climatic Fire Risk

The Harmattan; a dry, dusty northeast trade wind from the Sahara blows across West Africa between November and March, during which humidity can drop below 15% (Wikipedia, 2025). Fuel moisture content declines monotonically as the dry season progresses (Burkle *et al.,* 2020), and combustible exhibit materials, temporary display structures, and textile elements reach their lowest moisture content during Harmattan months, reducing the ignition threshold and increasing fire spread rates (N'Datchoh *et al.,* 2015). Detection systems must therefore favour temperature-rated heat detectors resistant to Harmattan dust over photoelectric smoke detectors, and natural smoke ventilation must be calibrated for both wet-season and dry-season prevailing wind regimes (Okeke *et al.,* 2022; Chow *et al.,* 2022).

4.6.4 The Economic Imperative for Multipurpose Use

Trade fair complexes in Nigeria and across West Africa are predominantly seasonal operations and the facilities are used intensively for an annual or biannual event and then lie dormant for the remainder of the year, generating no revenue to service capital and operating costs (Oguejiofor, 2011). Multi-functional trade fair buildings are capable of serving more than one purpose simultaneously, promoting environmental, economic, socio-cultural, and aesthetic objectives through the spatial integration of space uses and activities; such spaces reduce overhead costs while generating diverse streams of revenue" (Kodei *et al.,* 2023). To achieve economic viability, permanent exhibition centres must be designed for year-round multipurpose programming accommodating conferences, concerts, sporting events, graduation ceremonies, and weddings in addition to the annual trade fair. This programming diversity has significant fire safety implications: the building will regularly be occupied by different user profiles with different fuel loads, occupant densities, and emergency preparedness levels. The fire safety strategy must accommodate the full range of foreseeable occupancy types through compartmentation that provides inherent fire safety under variable occupancy conditions (Hassanain *et al.,* 2022; Alfalah *et al.,* 2023).

Four contextual drivers together make the fire-responsive architecture approach both necessary and practically valuable in these settings: (i) absence of reliable regulatory enforcement; (ii) limited emergency service capacity and response time; (iii) seasonally elevated fire risk during the Harmattan period; and (iv) the economic imperative for year-round multipurpose use generating variable occupancy fire risk profiles. These four drivers are explicitly addressed in the design framework presented in Section 4.7.

4.7 Fire-Responsive Design Framework for Exhibition Centres in Developing Economies

4.7.1 Framework Overview and Design Philosophy

The fire-responsive design framework presented in this section translates the fire safety principles established in the literature review (Section 2), the transferable design lessons derived from the case study analysis (Sections 4.2–4.5), and the four contextual drivers characterised in Section 4.6 into a coherent, evidence-based set of design principles applicable to multifunctional exhibition centres in developing economy contexts. The framework is organised across five interdependent dimensions corresponding to the IFSS (2020) five fire safety principles, treated not as separate engineering specifications but as integrated design generators with spatial, structural, and material implications engaged from the earliest stages of the design process. The integration of fire safety engineering principles from the onset of the design process has significant potential to deliver a better building based on optimisation where all relevant design variables are considered simultaneously rather than sequentially (Mostafa *et al.,* 2024). Fire safety must be perceived as a design parameter rather than an additional constraint, and integrating fire safety into the iterative design process is crucial to producing buildings that are genuinely rather than nominally safe (Maluk *et al.,* 2017).

4.7.2 Dimension 1: Site Planning for Fire Safety

Site planning constitutes the first and most fundamental layer of fire safety provision. Four principles are derived from the case study analysis and calibrated to developing-economy contextual conditions. (i) A peripheral vehicular access road forming a continuous loop around the site boundary, with a minimum carriageway width of 6 metres and turnaround provisions at all dead-end service roads, also serves as the goods delivery route for exhibitor logistics demonstrating the compatibility of fire safety and operational requirements (International Code Council, 2021).

(ii) Provision of an on-site fire station or fire response post adjacent to the peripheral access road, essential in contexts where municipal response times regularly exceed five minutes and where the five-minute benchmark at which active suppression is most effective cannot be guaranteed (Silas *et al.,* 2021; Jokotade *et al.,* 2026).

(iii) Strategic distribution of fire hydrants ensuring no point on any building exterior is more than 90 metres from a hydrant (NFPA, 2024), coordinated with a dedicated overhead water reservoir providing fire suppression supply independent of mains pressure, an essential redundancy provision in developing-economy infrastructure contexts (FEMA, 2008).

(iv) Zoning of high fire-hazard uses such as storage facilities, electrical plant rooms, maintenance workshops, waste disposal areas, and fuel storage to the site periphery, spatially separated from main exhibition and public assembly spaces (Martins *et al.,* 2024).

4.7.3 Dimension 2: Passive Structural and Spatial Fire Protection

Three structural fire protection strategies are recommended within the framework. The first is concrete encasement of primary structural steel members; the most robust and maintenance-free protection method, particularly appropriate for developing economy contexts where the ongoing maintenance of intumescent coatings cannot be guaranteed. The second is intumescent coating of exposed structural steel where architectural expression of the structural system is a design priority, providing fire resistance ratings of up to two hours at appropriate dry film thicknesses (Lucherini *et al.,* 2022). The third strategy is the liquid-filled column system for buildings where structural steel columns form part of the external envelope. A minimum fire resistance period of 90 minutes is recommended for all primary structural elements, extended to 120 minutes in developing-economy contexts where fire brigade response times regularly exceed 30 minutes (Kodur *et al.,* 2020; Silas *et al.,* 2021).

The exhibition building should be composed of discrete interconnected halls each constituting an independent fire compartment separated by full-height fire-rated partition walls incorporating electromagnetic hold-open fire doors that close automatically on alarm activation (Hassanain *et al.,* 2022). Storage spaces should be designed as separate fire compartments, and service penetrations through compartment walls should be sealed with intumescent mastic and mineral wool firestopping. All wall and ceiling linings in public areas should achieve Class A or Class B surface spread of flame ratings, with the permanent building fabric entirely non-combustible to compensate for variable exhibitor fuel loads. In the Nigerian context, empirical testing of building materials has found significant variation in fire performance indices across commonly used construction materials, with direct implications for material selection (Omofunmi and Abiwo, 2019).

4.7.4 Dimension 3: Active Fire Safety Systems

The entire exhibition building should be protected by a fully automatic wet-pipe sprinkler system designed to NFPA 13 requirements for ordinary hazard occupancy. A dedicated overhead water reservoir of sufficient capacity to sustain full system demand for a minimum of 60 minutes without supplementary mains supply is a critical provision in developing-economy contexts where supply interruptions are common (FEMA, 2008; Oloke *et al.,* 2022). Heat detectors are specified as the primary detection technology for exhibition halls in the West African climatic context: they are more effective in high-ceiling spaces than smoke detectors for floor-level fires, and are resistant to false alarms from dust-laden Harmattan air (N'Datchoh *et al.,* 2015; Okeke *et al.,* 2022). Photoelectric smoke detectors are specified for enclosed circulation spaces, offices, and meeting rooms (Hassanain *et al.,* 2022). A two-stage alarm system is recommended throughout: an initial alert to the security control room, followed by full building evacuation signal; audible alarm, visual strobe lights, and public address announcement on confirmed alarm activation, embedding a human verification layer that reduces alarm fatigue in contexts where detection systems may experience false alarms due to maintenance lapses or climatic conditions (Alao *et al.,* 2021).

4.7.5 Dimension 4: Smoke Ventilation and Control

In single-storey exhibition halls, natural smoke venting through automatically opening roof vents with a combined free area of minimum 5% of the enclosed floor area is the recommended primary strategy, preferred because it does not depend on fan operation or electrical power availability, critical in developing-economy contexts where power supply continuity cannot be assumed (Chow *et al.,* 2022). Roof vents should be controlled by fusible links at 68°C and by electrical actuators connected to the fire detection system, with replacement air entering at low level through automatically opening louvres. Permanent roof vents at minimum 2% of the enclosed floor area should additionally be provided for continuous passive ventilation during normal operation, reducing heat and humidity accumulation during peak occupancy periods. Where atria are incorporated, a mechanical exhaust system at the crown of the atrium skylight, sized to maintain a smoke-free layer of at least 2.5 metres above the highest occupied floor for a minimum of 30 minutes, is required (Brzezinska and Bryant, 2022; Lei *et al.,* 2023). Protected escape stairs should be managed through pressurisation to prevent smoke ingress.

4.7.6 Dimension 5: Emergency Egress

The egress strategy must be calibrated for the maximum foreseeable occupant load under multipurpose programming conditions. For large exhibition halls with potential peak occupancies exceeding 1,000 persons, a minimum of four exits per hall is recommended, positioned on diagonally opposite sides to ensure no occupant is more than 30 metres from the nearest exit in any direction (NFPA, 2024). Exit doors should be double-leaf, outward-opening, fire-rated doors with panic hardware requiring only a single push to release ensuring that they remain accessible under panic conditions. Protected escape stairs in multi-storey elements should be enclosed in fire-rated construction achieving a minimum of 90 minutes' fire resistance. Emergency lighting from a central battery backup system with a minimum three-hour capacity should be provided throughout all exit routes, ensuring that egress routes remain navigable under total power failure, a realistic risk in developing-economy contexts. Photoluminescent exit signage ensures visibility in both powered and unpowered conditions. Refuge areas with direct communication links to the building's emergency control centre should be provided for persons with reduced mobility (Kizilkaya Oksuz *et al.,* 2023).

4.7.7 Lessons for Design in Developing Contexts Like Jos, Nigeria

Four specific design lessons follow directly from the five framework dimensions for architects working in developing-economy urban contexts.

Lesson 1: Design for enforcement absence: passive fire safety provisions must perform independently of post-construction management; active systems must have built-in redundancy for utility supply interruption; the building must be inherently safe rather than contingently safe (David *et al.,* 2019; Alao *et al.,* 2021; Kodur *et al.,* 2020).

Lesson 2: Design for infrastructure constraints: structural fire resistance should be increased to 120 minutes where fire brigade arrival within 30 minutes cannot be guaranteed; dedicated water storage provides suppression system independence from unreliable mains supply (Silas *et al.,* 2021; Nimlyat *et al.,* 2017; Jokotade *et al.,* 2026).

Lesson 3: Design for seasonal fire risk: specify temperature-rated heat detectors in large-volume exhibition spaces in Harmattan conditions and calibrate natural ventilation for both wet-season and dry-season prevailing wind regimes (N'Datchoh *et al.,* 2015; Okeke *et al.,* 2022; Chow *et al.,* 2022).

Lesson 4: Design for economic sustainability through fire-safe flexibility: fire-safe compartmentation is simultaneously a fire safety provision and a commercial enabler making simultaneous multipurpose programming possible, demonstrating that fire safety and operational flexibility are complementary values (Maluk *et al.,* 2017; Hassanain *et al.,* 2022; Alfalah *et al.,* 2023).

Table 2: Fire-Responsive Design Framework - Five Dimensions, Key Principles, and Developing-Economy Calibration

Dimension	Key Principles and Strategies	Developing-Economy Calibration
1. Site Planning	Peripheral access road (min. 6m width); on-site fire station; hydrants at maximum 90m intervals; hazardous use zoning to site periphery; building separation where internal compartmentation is not feasible	On-site fire station essential where municipal response exceeds 5-minute benchmark; overhead water reservoir provides suppression supply independence from unreliable mains
2. Passive Structural Protection	Concrete encasement or intumescent coating of structural steel; minimum 90-min fire resistance (FR); grouped hall compartmentation; fire-rated compartment boundaries; non-combustible permanent building fabric	Extend structural FR to 120 minutes where fire brigade response regularly exceeds 30 minutes; specify concrete encasement where ongoing maintenance of intumescent coatings cannot be guaranteed
3. Active Fire Safety Systems	Full wet-pipe automatic sprinkler system (NFPA 13); zoned heat and smoke detection; two-stage alarm with public address; exhibitor materials regulation as operational management complement	Dedicated overhead water reservoir (minimum 60-min autonomy) for mains supply independence; heat detectors preferred over photoelectric in dust-laden Harmattan conditions
4. Smoke Ventilation and Control	Natural roof vents minimum 5% of hall floor area; automatic and manual actuation; make-up air at low level; mechanical atrium exhaust sized for 2.5m smoke-free layer over 30 minutes	Natural venting preferred for power-supply independence; calibrate for both wet-season and dry-season Harmattan prevailing wind regimes; permanent vents (min. 2%) for year-round passive ventilation
5. Emergency Egress	Minimum four exits per hall; maximum 30m travel distance; panic hardware on all exit doors; 90-min FR protected escape stairs; 3-hour battery emergency lighting; photoluminescent directional signage; refuge areas for persons with mobility impairments	Integrate egress routes with primary visitor circulation for legibility; photoluminescent signage ensures exit visibility in power-failure conditions prevalent in developing-economy infrastructure contexts

4.8 Discussion

The framework presented in Section 4.7 proposes a reorientation of the architectural design process: a shift positioning fire safety as a generative input rather than a corrective output. This distinction is at once simple and consequential; it is the difference between a building whose safety is inherent to its spatial logic and a building whose safety is appended to an otherwise complete design. The general consensus among fire safety engineering professionals is that integration of competent fire safety principles from the onset of the design process has significant potential to deliver a better building, based on optimisation where the best solution is found through consideration of all relevant design variables simultaneously rather than sequentially (Mostafa *et al.,* 2024). Yet the practical adoption of this integrated philosophy has been uneven and inconsistent particularly in developing economies where the dominant practice remains one of minimum prescriptive compliance (Maluk *et al.,* 2017; Kodur *et al.,* 2020). The fire-responsive architecture framework is positioned as a design-practice response to this gap.

A persistent assumption that the fire-responsive architecture concept directly contests is that fire safety requirements constrain architectural freedom. Contemporary research demonstrates that fire-resistant design strategies can be adapted to open layouts and aesthetically ambitious programmes without compromising spatial quality (Erces *et al.,* 2024). The Leipzig Trade Fair's Glass Hall demonstrates that one of the most architecturally ambitious building envelopes of the late twentieth century can be made fire-safe without compromising its spatial drama. The Mountain America Exposition Center demonstrates that a fully sprinklered, rigorously compartmented exhibition facility can simultaneously be one of the most operationally flexible event venues in its region. Performance-based structural fire engineering provides opportunities to develop designs optimised for project economics, aesthetics, and lifecycle maintenance without compromising fire safety (Gernay *et al.,* 2023). For developing-economy contexts, this directly counters the economic argument that fire safety provisions are unaffordable additions.

The framework is explicitly generalisable. By grounding its five dimensions in comparative evidence from three case studies spanning three continents and expressing its provisions as design principles rather than building specifications, the framework is directly applicable to any exhibition centre in a developing economy context where the four contextual drivers are present. Structural fires resulted in approximately 401,000 deaths per year globally from 1993 to 2020, attributed to urbanisation, congestion, increased construction, and the lack of implementation of safety rules and regulations, all of which characterise the developing-economy urban condition (Walls *et al.,* 2021). The framework's most important transferability feature is its independence from sophisticated regulatory approval processes and computational validation tools, making it applicable within the competence of any registered architect in any regulatory environment. Future research should prioritise: computational validation through CFD simulation or AI-assisted fire scenario analysis tools (Zeng and Huang, 2025; Zeng *et al.,* 2024); primary fieldwork-based post-occupancy fire safety assessment of existing Nigerian public assembly buildings (Olatunji *et al.,* 2019; Nimlyat *et al.,* 2017); development of context-specific fire safety design guidelines for West African public assembly buildings; and integration of fire safety performance with sustainability and lifecycle cost assessment.

5. CONCLUSION

This paper has advanced the concept of fire-responsive architecture; an approach in which fire safety is treated not as a regulatory compliance endpoint but as a generative design principle embedded in spatial organisation, structural selection, material specification, and site planning from the earliest stages of the design process. The paper has applied this concept to the specific typological, contextual, and institutional conditions of multifunctional exhibition centres in developing economy cities, developing a five-dimensional framework that is evidence-based, architecturally actionable, and expressly calibrated to contexts in which regulatory enforcement is unreliable, emergency service capacity is constrained, seasonal fire risk is variable, and year-round multipurpose programming is economically essential.

Three substantive contributions are identified: a critical thematic synthesis of fire safety literature as it pertains to the exhibition centre typology, establishing that the five common principles of fire safety are most effectively served when embedded in the architectural design process from the outset (Maluk *et al.,* 2017; Kodur *et al.,* 2020; Park *et al.,* 2013); a structured comparative analysis demonstrating that fire safety and spatial flexibility are compatible values, that integration into primary architectural elements produces better outcomes than technical afterthoughts, and that design-embedded fire safety must be supported by operational management systems (Hassanain *et al.,* 2022; Alfalah *et al.,* 2023); and the five-dimensional fire-responsive design framework itself, with four explicit lessons for developing economy contexts (David *et al.,* 2019; Silas *et al.,* 2021; Alao *et al.,* 2021; N'Datchoh *et al.,* 2015).

The contextual analysis confirms that the conditions driving the need for fire-responsive design are systemic across sub-Saharan Africa, where only four of 48 countries have updated building regulatory frameworks within the past decade, and where adopted regulations are often fragmented, lack coordination, and are insufficiently enforced (Mulenga and Mwansa, 2025). The architectural profession has both the opportunity and the responsibility to respond through design intelligence rather than regulatory compliance alone (Omisore *et al.,* 2025). Fire safety is among the most fundamental needs that buildings serve, and the frequency and severity of fire incidents in Nigerian public buildings, with over 266 outbreaks in the first half of 2024 alone (Sholanke *et al.,* 2025) confirm that current design practice is not adequately meeting it. Trade fair centres, conference halls, markets, stadiums, and worship centres across Nigeria and the wider African continent are regularly occupied by thousands of people in conditions recognised internationally as inadequate. The buildings that house these activities are designed by architects. The safety of the people in them is, in significant measure, an architectural responsibility and fire-responsive design is the profession's most direct and most practically available means of meeting it.

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