



IMPLEMENTING SAFETY MEASURES IN THE DESIGN OF FACTORIES; A PROPOSED LITHIUM BATTERY FACTORY, KOGI STATE.

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Abstract

This study examines the architectural and safety implications of establishing a lithium-ion battery (LIB) manufacturing facility in Kogi State, Nigeria, within the context of the country's growing strategic interest in domestic value addition from its lithium resources. The research develops a safety-integrated architectural framework grounded in the principles of Design for Safety (DfS), aimed at mitigating the inherent hazards of LIB production. Using a qualitative and analytical approach, the study synthesizes existing literature on LIB manufacturing risks, particularly thermal runaway, and evaluates international safety standards for adaptation to the Nigerian context. Findings indicate that LIB production presents critical hazards, including high-intensity fires and the emission of toxic gases such as hydrogen fluoride and carbon monoxide. These risks are further exacerbated by local challenges, including weak regulatory enforcement, infrastructural deficits, and the prevalence of substandard construction materials. The study demonstrates that reliance on external regulatory compliance is insufficient in such contexts, necessitating an intrinsically safe architectural approach. It proposes a layered risk-mitigation strategy that integrates passive fire protection, explosion control, chemical containment, and advanced ventilation systems into the early stages of design. The paper concludes that the successful development of a lithium battery factory in Nigeria depends on embedding safety within the architectural process itself. It recommends the adoption of robust DfS frameworks, precise material specifications, and context-sensitive design strategies to ensure environmental sustainability, operational safety, and long-term resilience.

Keywords: Lithium-ion Battery, Design for Safety (DfS), Thermal Runaway, Industrial Architecture, Hazard Mitigation.

Introduction

The global energy storage market is projected to grow by five to ten times in the next decade, driven by the transition toward renewable energy and electric vehicles (Yusuf et al., 2022; CED Engineering, 2023). Nigeria is strategically positioned for this shift due to commercial quantities of lithium ore in states like Kogi (Yusuf et al., 2022). Establishing a domestic LIB value chain is expected to foster economic development and high-value job creation. Kogi State specifically offers a unique geological profile of crystalline Basement Complex and Cretaceous sediments, providing both raw mineral deposits and local construction materials like granite (Olanrewaju et al., 2023; Olanrewaju and Abiodun, 2023).

However, LIB manufacturing involves complex hazards, primarily thermal runaway (OSHA, 2022). This self-amplifying feedback loop leads to rapid temperature increases, electrolyte vaporization, and potential explosions (Mell, 2013; Kwon, 2023). These events release toxic gases, including hydrogen fluoride (HF) and carbon monoxide (CO), which can reach concentrations 500 times higher than OSHA permissible limits (OSHA, 2022; TEEX, 2024; Gasmet, 2025). In Kogi, these risks are exacerbated by local environmental stressors, such as existing water pollution in urban centers (Ifatimehin et al., 2021; Tijani and Ajayi, 2025). The Nigerian construction industry also presents a "hazard multiplier" due to weak regulatory enforcement and the use of substandard materials (Fadason et al., 2017; Ogbonna and Nwankwo, 2023). Consequently, safety cannot rely on external compliance; it requires a proactive, structurally robust Design for Safety (DfS) framework (OSHA, 2023; EHS University of Toronto, 2023).

The study is guided by the following technical and architectural objectives:

1. To identify and categorize the primary thermal, chemical, and electrical hazards inherent in the lithium battery manufacturing process.
2. To analyze international best practices and architectural design principles for mitigating these hazards, with a focus on containment, ventilation, and fire protection.
3. To evaluate the specific environmental, geological, and regulatory context of Kogi State, Nigeria, to inform the design process.
4. To propose a practical architectural design framework and recommendations that integrate these safety measures while considering the local context.

This research fills a significant gap in the academic literature concerning industrial architectural safety in Nigeria, particularly for the emerging, high-risk sector of battery production. While previous studies have examined Nigeria's potential for LIB production (Yusuf et al., 2022), none have provided a detailed architectural blueprint for a safe facility. The study directly addresses a real-world problem by offering a foundational design guide for developers and practitioners, contributing to the development of a safe and sustainable domestic industrial base.

This research is strictly limited to the architectural and engineering design phase of a lithium battery factory. The scope includes site selection criteria, building layout and planning, structural integrity, material specification, and the design of both passive and active safety systems. The study does not extend to detailed operational safety protocols, human resources management, or the specific electrochemical processes of battery production, as these fall outside the primary domain of architectural design.

2.0 Literature Review and Theoretical Framework

The literature review and theoretical framework for this study are structured around the synthesis of technical LIB hazards, international architectural mitigation strategies, and the unique socio-technical context of Kogi State, Nigeria.

2.1 Conceptual Framework

The conceptual framework is an iterative, multi-domain model titled the "Integrated Safety Design Strategy".

- a) **The Domain of Hazards:** This identifies the extreme risks inherent in LIB production. Thermal runaway is the primary catastrophic threat, characterized by a self-sustaining exothermic chain reaction (Mell, 2013; Kwon, 2023). This process releases toxic gases including HF, CO, and volatile organic compounds (VOCs) such as ethylene and acetylene (OSHA, 2022; Gasmets, 2025; TEEX, 2024).
- b) **The Domain of Design Principles:** This focuses on architectural solutions, primarily guided by international standards like NFPA 855 (National Fire Protection Association, 2024). Key principles include compartmentalization using passive fire protection (PFP) to contain fires at the source, and explosion mitigation using ducted relief venting to protect structural integrity (SafetyCulture, 2025; Villotech, 2024).
- c) **The Domain of Local Context:** This introduces the "hazard multiplier" of the Nigerian environment. It addresses the lack of context-specific national codes and the pervasive use of substandard materials, which requires the building to be self-protecting (Fadason et al., 2017; Ogbonna and Nwankwo, 2023).

2.2 Theoretical Framework

The research is anchored in three core theoretical pillars:

1. **Design for Safety (DfS) Principle:** Also known as Prevention through Design (PtD), this advocates for the proactive elimination or reduction of hazards at the earliest possible stage (OSHA, 2023). DfS is ethically sound and economically prudent, as the ability to influence safety is highest during pre-construction (EHS University of Toronto, 2023).
2. **Sustainable and Green Architecture:** This integrates environmental consciousness and resource efficiency throughout a building's entire lifecycle (Nugraha and Zaini, 2024). For a facility in Kogi, this requires responsible waste management and the protection of local ecosystems from chemical contamination (Elkington, 1997; Ifatimehin et al., 2021).
3. **Safe-and-Sustainable-by-Design (SSbD):** This represents a paradigm shift toward integrating safety, sustainability, and circularity from the outset of innovation (Remle et al., 2018). It utilizes Life Cycle Thinking (LCT) to systematically assess impacts from raw material extraction (lithium mining) to manufacturing and end-of-life recycling.

2.3 Theoretical and Empirical Studies

Theoretical research focuses on the systematic identification of hazards using analytical approaches such as Process Hazard Analysis (PHA) (Center for Chemical Process Safety, 2011). Methodologies such as HAZOP (Hazard and Operability Study) and Failure Mode and Effects Analysis (FMEA) are used to evaluate equipment failures and process deviations (Center for Chemical Process Safety, 2011). Architectural literature emphasizes that designers have an ethical responsibility to specify materials with a full understanding of their life-cycle impacts, prioritizing transparency to reduce environmental toxicity (AIA, 2014). This is particularly critical in the Nigerian context, where surveys reveal a "Safety Awareness Gap", approximately 89% of built-environment professionals understand DfS theoretically, yet actual implementation remains negligibly low due to systemic failures and a reliance on foreign codes (Umeokafor et al., 2022; Manu et al., 2020).

Empirical studies confirm that LIB hazards stem from high energy density and flammable organic electrolytes (OSHA, 2025; OSHA, 2022). Thermal runaway fires can reach extreme temperatures, recorded at averages of 5000°F, which are significantly higher than typical gas fires (Levin Simes, 2024). During such events, CO concentrations can reach 500 times the OSHA permissible limit, and formaldehyde levels can exceed safety limits by 150 times (TEEX, 2024; Gasmeter, 2025). Furthermore, empirical research into Safe-and-Sustainable-by-Design (SSbD) frameworks suggest that over 80% of industrial accidents can be traced back to decisions made during the preliminary design phase (Joint Research Centre, 2025). FAA fire tests demonstrate that internal defects or physical impacts can trigger rapid overheating, and the time from the first sign of smoke to a gas explosion in a closed environment can be as little as 20 seconds (FAA, 2016; An and Li, 2025). These empirical realities prove that a design compliant in a developed environment may be dangerously inadequate in Nigeria due to the lack of supportive regulatory infrastructure, necessitating intrinsic architectural resilience (Ogbonna and Nwankwo, 2023; Fadason et al., 2017).

3.0 Methodology

The methodology for this study is a multi-faceted approach designed to develop a conceptual and prescriptive architectural framework from established knowledge.

3.1 Research Design

This study employs a qualitative and analytic research design. This descriptive methodology is suitable for architectural studies as it allows for the nuanced analysis of design principles, ethical considerations, and contextual factors that cannot be quantified in a purely statistical manner. The research does not involve primary field data collection but instead utilizes a systematic review and critical synthesis of existing academic literature and technical standards to build a new, coherent design model.

3.2 Area of the Study

The study focuses on Kogi State, Nigeria, located at the confluence of the Niger and Benue rivers. Kogi possesses a unique geology, featuring a crystalline Basement Complex on its western flank and Cretaceous to Recent sediments on its eastern flank, making it rich in lithium-bearing pegmatites and construction minerals like granite (Olanrewaju et al., 2023; Olanrewaju and Abiodun, 2023). However, urban water bodies in Kogi are of poor quality due to indiscriminate waste disposal and unregulated industries, which underscores the need for a factory design that is environmentally responsible (Ifatimehin et al., 2021; Tijani and Ajayi, 2025).

3.3 Population and Sampling

The population of this research comprises the total body of academic literature, technical publications, and regulatory documents relevant to industrial architectural design, safety for hazardous materials, and the Nigerian socio-economic context. Purposive sampling was used to select high-relevance academic and institutional publications, such as NFPA standards and

empirical studies on the Nigerian construction industry, ensuring the data collected was directly pertinent to the research questions.

3.4 Inclusion and Exclusion Criteria

To ensure the study's precision and relevance, specific criteria were applied during the systematic review:

1. **Inclusion Criteria:** (1) Peer-reviewed academic journals and conference proceedings published within the last decade; (2) Official technical standards and safety manuals from authoritative bodies like NFPA and OSHA; (3) Empirical studies specifically focused on the Nigerian construction industry or Kogi State's geology/environment; (4) Research detailing the technical hazards of lithium-ion battery manufacturing and architectural mitigation strategies.
2. **Exclusion Criteria:** (1) Broad studies on electrochemical chemistry that lack architectural or engineering implications; (2) Research on industrial sectors unrelated to hazardous material handling; (3) General architectural studies that do not integrate technical safety or industrial resilience; (4) Non-authoritative or anecdotal reports lacking technical validation.

3.5 Data Collection and Analysis

Data was collected exclusively from secondary sources, including authoritative bodies like the National Fire Protection Association (NFPA) and the Occupational Safety and Health Administration (OSHA) (OSHA, 2022; National Fire Protection Association, 2024). The data was analyzed using a qualitative, thematic analysis approach involving four primary steps:

1. Hazard Identification: Categorizing LIB manufacturing hazards from empirical studies.
2. Solution Mapping: Pinpointing architectural and engineering solutions for each hazard from international literature.
3. Contextual Evaluation: Examining the geological and regulatory conditions of Kogi State and Nigeria.
4. Critical Synthesis: Integrating these bodies of information to develop a practical design framework.

4.0 Results and Discussion

The results of this research demonstrate that a lithium battery manufacturing facility presents a complex, multi-faceted array of hazards that require a robust, layered architectural response.

4.1 Identification of Hazards and Their Architectural Implications

The manufacturing process is fraught with three primary categories of risk:

- a. **Thermal and Fire Hazards:** Thermal runaway is the paramount risk, producing an exothermic chain reaction that generates rapid temperature increases and catastrophic fires (Mell, 2013; Kwon, 2023). This event is fueled by oxygen released from the cathode material, making it extremely difficult to extinguish. Architecturally, this necessitates a design that can contain a fire at its source and prevent propagation (Kwon, 2023).

- b. **Chemical Hazards:** LIB electrolytes consist of flammable liquids and salts, such as lithium hexafluorophosphate, which reacts with water to form corrosive hydrogen fluoride (HF) (OSHA, 2022). During thermal events, these chemicals off-gas toxic and flammable vapors (Kwon, 2023). This requires advanced capture systems and the specification of chemically resistant materials.
- c. **Physical and Electrical Hazards:** Gas pressure buildup inside cells can cause swelling and rupture, leading to explosions (Mell, 2013). High-capacity battery packs also present electrical shock and arc flash hazards, requiring insulated terminals and appropriate protective provisions (EHS University of Washington, 2023).

4.2 Architectural Design Principles for Hazard Mitigation

Based on the identified hazards, the framework integrates four core principles of industrial safety.

4.2.1 Principle 1: Compartmentalization and Fire Containment

Compartmentalization is the foundational principle of passive fire protection (PFP) (SafetyCulture, 2025). The design must divide the factory into fire-rated zones using specialized walls and floors. This study specifies materials with precise fire-resistance ratings, including gypsum board (which releases steam to slow heat transfer), mineral wool insulation, and intumescent paint for structural steel, which expands into an insulating char layer (SafetyCulture, 2025). These measures should be rated to withstand extreme temperatures for 30 to 240 minutes to maintain structural integrity and safe evacuation paths.

4.2.2 Principle 2: Explosion Mitigation

Mitigation requires two strategies: venting and isolation (Villotech, 2024). While explosion venting panels are cost-effective, internal venting can cause secondary dust explosions and injure personnel (International Dust Explosion, 2024). Therefore, this framework explicitly prioritizes the safer, though more expensive, approach of ducting vents to the outside atmosphere, as recommended by NFPA 68 (International Dust Explosion, 2024). This is essential in a context like Nigeria, where there is a high risk of choosing cheaper, less safe internal venting options due to weak oversight.

4.2.3 Principle 3: Ventilation and Gas Management

The facility must employ a multi-layered approach, combining general mechanical ventilation with a robust local exhaust ventilation (LEV) system (OSHA, 2022; US Chemical Storage, 2024). LEV is critical for capturing toxic HF gas at its source. The design includes hoods, ducts, and fans that exhaust contaminated air through a dedicated stack with no recirculation.

4.2.4 Principle 4: Chemical Containment and Material Specification

Architectural design must support the safe handling of chemicals through physical segregation and secondary containment (EHS University of Wisconsin, 2023). Given the local prevalence of substandard materials, designers must go beyond generic specifications. This framework mandates the use of exact polymer types, such as thermoplastic polyurethane (TPU) with

proven resistance to the specific carbonates and acids found in LIB manufacturing, and polyethylene for secondary containment liners and trays (Americhem, 2024; Covestro, 2024; EHS University of Wisconsin, 2023).

Hazard Typology	Inherent Risk	Architectural/Engineering Control Measures
Thermal and Fire	Thermal Runaway, Propagation	Fire-rated compartmentalization (gypsum/wool/intumescent)
Chemical	Toxic Gas Release (HF, H ₂ , CO)	Local Exhaust Ventilation (LEV) to source; no recirculation
Physical/Explosive	Pressure Buildup/Rupture	Explosion venting panels ducted to the exterior
Contamination	Electrolyte Spills	Polyethylene secondary containment trays; segregation

Material	Application in Factory Design	Key Resistance Properties
Gypsum Board	Walls and ceilings	Fire-rated for 30-240 mins; releases steam under heat
Intumescent Paint	Structural steel coating	Expands to form an insulating char layer
Polyethylene	Liners and containment trays	High resistance to corrosive acids and alkaline solutions
TPU	Surface coatings	Tailorable chemical resistance to LIB media/carbonates
Granite	Foundations; non-critical elements	Durable local material; high compressive strength

4.3 Integration of Design with the Nigerian Context

The framework adapts these principles to Kogi State by voluntarily adopting international best practices (like NFPA 855) to compensate for weak local enforcement (National Fire Protection Association, 2024). It also incorporates a sustainability ethos, utilizing locally abundant materials such as granite from Kogi's Basement Complex for foundations and exterior cladding to ensure durability while supporting the local economy (Olanrewaju et al., 2023). Furthermore, the design prioritizes environmental protection to prevent the pollution of local water bodies, a significant local concern.

4.4 Proposed Safety-Integrated Architectural Framework

The findings are synthesized into a phased framework:

- Phase 1:** Pre-Design: Conduct a Hazard Mitigation Analysis (HMA) per NFPA 855 and evaluate local geology/environmental conditions.
- Phase 2:** Conceptual Design: Apply Design for Safety (DfS) to physically segregate high-risk manufacturing and establish clear evacuation routes.

3. **Phase 3:** Schematic Design: Detail safety systems, including passive fire protection, exterior-ducted venting, and LEV.
4. **Phase 4:** Material Specification: Provide exact technical specifications and resistance ratings for all critical materials to prevent substandard substitution.

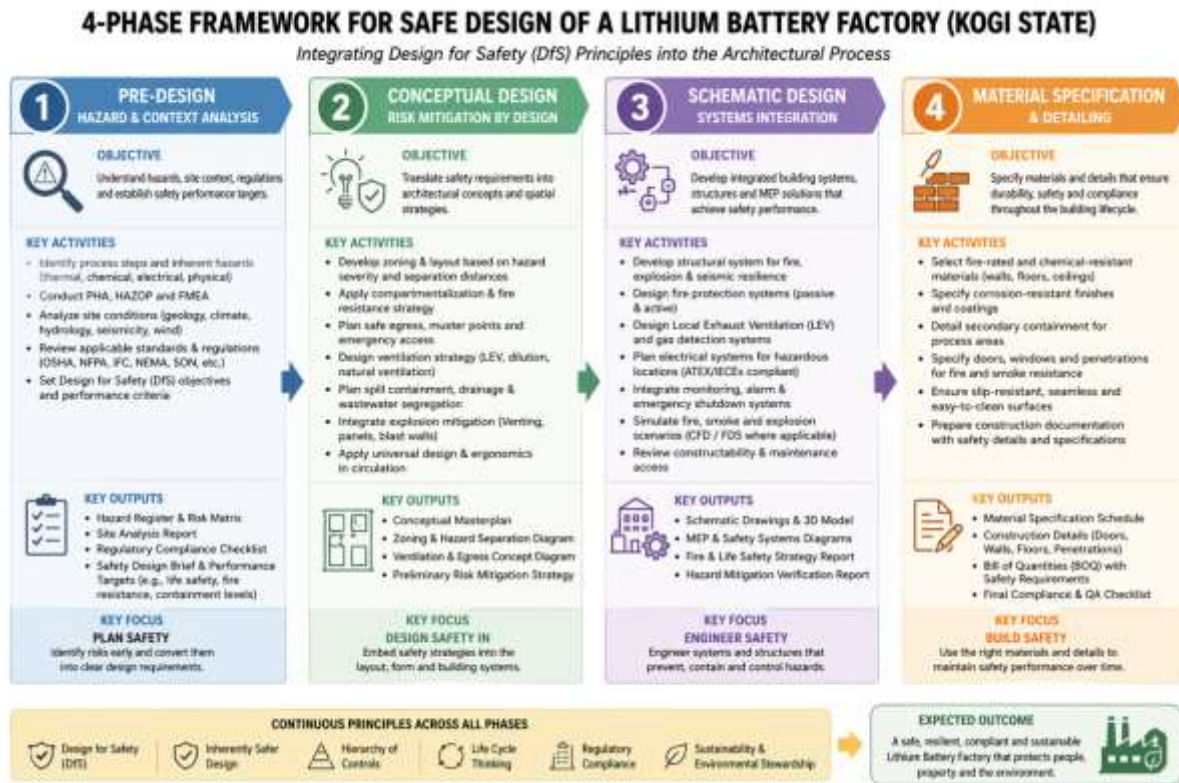


Figure 1: 4-phase lithium battery factory design framework; Source: Researcher

5.0 Conclusion and Recommendations

The establishment of a lithium battery factory in Kogi State offers immense socio-economic potential but requires a rigorous architectural framework to mitigate inherent manufacturing hazards. In the Nigerian context, where regulatory enforcement is weak and substandard materials are prevalent, safety cannot rely solely on external compliance (Fadason et al., 2017; Ogbonna and Nwankwo, 2023). Instead, it must be achieved through intrinsic, structurally robust design. A proactive Design for Safety (DfS) approach that engineers out hazards from the beginning is the only defensible blueprint for ensuring the facility does not become a liability to the community and the environment (OSHA, 2023).

Based on the study, the following actions are recommended:

1. **Architectural:** Implement a multi-layered hazard mitigation framework, including passive fire protection (PFP), ducted explosion venting (NFPA 68), and LEV systems.
2. **Materials:** Specify exact polymer types (e.g., TPU, XLPE) for chemical resistance to prevent containment breaches.
3. **Policy:** The Nigerian government should modernize national building codes to incorporate international standards like NFPA 855 and enforce domestic value addition (beneficiation) policies (Nigeria's Critical Mineral Wealth, 2025).

4. Socio-Economic: Integrate infrastructure development (roads/water) into the project via public-private partnerships and establish a circular economy model through co-located battery recycling facilities.

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