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RESEARCH ARTICLE

Architectural Strategies for Enhancing Hygiene and Operational Efficiency in Abattoir Facilities: A Design-Based Study of Ngor Okpala, Imo State, Nigeria

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ABSTRACT

Abattoir facilities in Nigeria and other developing countries are characterised by persistent hygiene deficiencies, inadequate spatial planning, and operational inefficiencies that pose significant public health risks and undermine meat safety standards. This article examines architectural design strategies for enhancing hygiene standards and operational efficiency in abattoir facilities, using the proposed Ngor Okpala Meat Processing Facility in Imo State, Nigeria, as a design-based case study. Adopting a qualitative design-based research methodology, the study draws on an extensive review of international design guidelines, regulatory standards, and contemporary empirical literature to identify evidence-based architectural strategies applicable to the Nigerian rural abattoir context. Key findings reveal that the predominant hygiene challenges in conventional Nigerian abattoirs — including the absence of clean and dirty zone separation, inadequate drainage, poor ventilation, and deficient water supply — are primarily rooted in architectural planning failures rather than operational shortcomings alone. The proposed design for the Ngor Okpala Abattoir integrates six core architectural strategies: functional zone separation; unidirectional process flow; hygienic material selection; engineered drainage systems; climate-responsive ventilation and lighting; and integrated waste and effluent management. The study demonstrates that a contextually responsive, evidence-based architectural approach can substantially improve hygiene compliance and operational performance in rural meat processing facilities. Findings contribute to the body of architectural and public health evidence on the design of food processing infrastructure in developing countries, and provide a replicable design framework for similar facilities across southeastern Nigeria and sub-Saharan Africa.

Keywords: *Abattoir design; Architectural strategies; Hygiene; Operational efficiency; Ngor-Okpala; Nigeria*

1. INTRODUCTION

The abattoir – a purpose-built facility where livestock are humanely slaughtered, and their carcasses hygienically processed to produce meat and meat products fit for human consumption, is one of the most critical and technically demanding

categories of food processing infrastructure in any society (Gracey & Collins, 2016; Thanappan, 2022). Beyond its primary function as a site of meat production, the abattoir serves simultaneously as a public health facility, a veterinary inspection point, an environmental management concern, and an economic asset of significant importance to local food systems and livelihoods. The quality of abattoir design, construction, and management is therefore directly consequential not only for the safety and quality of meat produced, but also for the health of workers, surrounding communities, and the broader environment (Hossain et al., 2025).

Globally, abattoir design has evolved considerably over the past three decades, from rudimentary open-air slaughter grounds to sophisticated, highly regulated meat processing complexes governed by stringent international standards. These standards — established by the Food and Agriculture Organisation of the United Nations (FAO), the World Health Organisation (WHO), and the Codex Alimentarius Commission (CAC) — prescribe specific architectural requirements for spatial zoning, unidirectional process flow, drainage systems, ventilation, lighting, water supply, and waste management, all of which are integral to the safe and hygienic production of meat (FAO, 1991; CAC, 2005). While these standards date to the foundational period of international food safety regulation, they remain the authoritative global benchmarks and continue to be applied and referenced in contemporary research (Ovuru et al., 2024; Agriculture Institute, 2026).

In developing countries, however, compliance with these standards remains exceptionally low. According to the Registrar of the Veterinary Council of Nigeria, only three standard abattoirs exist across the country's thirty-six states and the Federal Capital Territory, with the remainder operating as substandard or informal slaughter facilities (Ovuru et al., 2024). A scoping review encompassing fourteen studies conducted predominantly in Nigeria between 2015 and 2023 documented consistent and widespread evidence of substandard hygiene practices across slaughterhouse facilities in the country, identifying poor infrastructure as the primary structural determinant (Hossain et al., 2025). Poor sanitary conditions, absence of hygienic spatial planning, inadequate drainage and waste management systems, and the lack of ante- mortem and post-mortem inspection facilities are among the most frequently cited structural deficiencies (Ovuru et al., 2024; Dahiru et al., 2025).

In Imo State, southeastern Nigeria, evidence of bacterial contamination linked directly to abattoir hygiene failures has been documented in the Owerri zone, highlighting the severity of the problem at the local level (Uzoigwe et al., 2021). Ngor Okpala, a predominantly rural local government area in Imo State with a significant agrarian economy and substantial livestock trade, currently lacks a purpose-designed, hygienically compliant meat processing facility. Animal slaughter is conducted in informal, makeshift settings that bear none of the spatial, environmental, or hygiene provisions required by national or international standards. The public health, economic, and food safety implications of this situation are considerable and demand urgent, evidence-based architectural intervention.

Architectural design, as a discipline that integrates spatial planning, environmental engineering, materials science, and human factors, is uniquely positioned to address the systemic hygiene and operational challenges of abattoir facilities. Yet the contribution of architecture as a distinct professional and academic discipline to the resolution of abattoir hygiene problems in Nigeria has received limited scholarly attention. Most existing studies approach the problem from veterinary public health, food science, or environmental management perspectives, with little examination of how deliberate architectural strategies — spatial organisation, material selection, drainage engineering, ventilation design, and zonal planning — can serve as primary vehicles for hygiene improvement and operational optimisation (Thanappan, 2022; Shija et al., 2020). This article seeks to address that gap through a design-based investigation of the proposed Ngor Okpala Abattoir as a contextually grounded case study.

The vast majority of abattoir and slaughter facilities operating across Nigeria, including those in rural and peri-urban areas of Imo State, continue to function in conditions that fall far below the minimum hygiene and design standards prescribed by international regulatory authorities. A comprehensive scoping review of slaughterhouse hygiene practices published in PLOS ONE confirmed that one-third of the fourteen eligible studies identified were from Nigeria alone, consistently documenting deficient personal and environmental hygiene practices attributable to inadequate facility infrastructure (Hossain et al., 2025). In southeastern Nigeria, studies have found that fewer than half of abattoir workers cleaned work surfaces with soap and water — a direct consequence of the absence of adequate sanitary infrastructure in the facilities where they worked (Adeyemi & Oyedele, 2022).

These conditions are not merely the result of ignorance or negligence on the part of abattoir workers and operators. They are, in significant measure, a product of fundamental architectural and planning failures: the absence of functional zone separation between clean and dirty operations; inadequate or non-existent drainage systems; deficient water supply infrastructure; poor ventilation that promotes moisture accumulation and microbial growth; insufficient lighting for ante-mortem and post-mortem inspection; and the absence of integrated waste and effluent management systems (FAO, 1991; Ovuru et al., 2024; Thanappan, 2022). The consequences manifest in the contamination of meat with pathogenic microorganisms — including Escherichia coli, Salmonella, and Staphylococcus species — which are implicated in foodborne illnesses of significant public health consequence (Ovuru et al., 2024; Uzoigwe et al., 2021; Dahiru et al., 2025).

In Ngor Okpala, Imo State, the absence of any formal, architecturally designed meat processing facility means that the totality of these hygiene and operational deficiencies is present without mitigation. No study in the available literature has specifically examined the architectural design dimensions of abattoir facilities in Ngor Okpala, or has developed a contextually grounded design framework for improving meat processing hygiene and efficiency in this locality. This study addresses that gap directly, contributing an original design-based analysis and evidence-based architectural framework to the existing body of knowledge.

The aim of this study is to examine and critically appraise evidence-based architectural design strategies for the enhancement of hygiene standards and operational efficiency in abattoir facilities, utilising the proposed meat processing facility in Ngor Okpala, Imo State, Nigeria, as a contextually grounded design-based case study.

In pursuance of the foregoing aim, the study specifically seeks to:

i. identify hygiene-related challenges associated with conventional abattoir facilities in Nigeria;
ii. examine operational inefficiencies arising from poor spatial planning and facility layout in abattoirs;
iii. evaluate architectural design strategies that can enhance hygiene standards and operational efficiency in meat processing facilities; and
iv. assess the potential contributions of the proposed Ngor Okpala Abattoir design toward improved facility performance.

This study makes a timely and multidimensional contribution to scholarship and practice at the intersection of architecture, public health, and food systems infrastructure. From an academic perspective, it addresses a significant gap in the built environment literature by foregrounding the role of architectural design as a primary mechanism for improving abattoir hygiene and operational performance in developing-country contexts. It demonstrates the applicability of design-based research methodology in architectural investigations of industrial food processing infrastructure, contributing methodological clarity to this under-researched area (Groat & Wang, 2013; Cahyono et al., 2021).

From a practical standpoint, the study provides a replicable, evidence-based design framework grounded in international standards (FAO, 1991; CAC, 2005; WHO, 1983) and adapted to the specific environmental, economic, and regulatory

conditions of rural southeastern Nigeria. The proposed design for the Ngor Okpala Abattoir offers a tangible, implementable model that local government authorities, the Federal Ministry of Housing and Urban Development, and state planning agencies can adopt or adapt for similar facilities across Imo State. The study's significance is further underscored by the documented public health burden of poor abattoir hygiene in Nigeria, including zoonotic disease transmission, foodborne illness outbreaks, and the economic losses associated with meat spoilage and condemnation (Ozoji, 2021; Hossain et al., 2025).

2. LITERATURE REVIEW

Concept of Abattoir Facilities

An abattoir, also known as a slaughterhouse or meat processing facility, is broadly defined as a purpose-built establishment in which livestock are humanely slaughtered and their carcasses processed under hygienic conditions to produce meat and meat products fit for human consumption (FAO, 1991; Thanappan, 2022). The term encompasses a wide spectrum of facility types, ranging from small-scale rural slaughter slabs to large, fully mechanised modern abattoirs integrated with cold chain infrastructure, by-product processing plants, and effluent treatment systems. The FAO (1991) broadly recognises three categories of slaughterhouses in developing countries: modern slaughterhouses, old or formal-but-outdated slaughterhouses, and informal makeshift slaughter slabs or premises. Ovuru et al. (2024) observe that the latter two categories predominate across sub-Saharan Africa, including Nigeria, with the majority operating without reference to established design or hygiene standards.

The concept of the abattoir as a regulated food safety infrastructure emerged alongside the development of veterinary public health as a discipline and the recognition of the abattoir as a critical control point in the meat supply chain (Gracey & Collins, 2016). Modern abattoir design is informed by a set of well-established functional requirements that reflect the integration of veterinary science, environmental engineering, food technology, and architectural planning. As Thanappan (2022) articulates, the guiding principle for designing any abattoir is to provide all related services under hygienic conditions, with the facility's spatial organisation serving as the primary mechanism for preventing cross-contamination between clean and dirty operational zones. In Nigeria, the structuring of slaughter facilities has historically been governed by local government authorities under the Local Government Reform Act of 1976, a framework that Ozoji (2021) identifies as contributing to the fragmented and underinvested state of abattoir infrastructure across the country.

The essential functional spaces required in a standard abattoir include: the lairage or animal holding area; ante-mortem examination and isolation facilities; the stunning and humane slaughter section; the dressing and carcass processing hall; post-mortem inspection facilities; a veterinary office; chilling and cold storage rooms; by-product processing and rendering areas; an effluent treatment plant; and personnel hygiene and welfare facilities (FAO, 1991; Thanappan, 2022; Shija et al., 2020). The spatial relationships between these functional areas, and the directional flow of animals, products, personnel, and waste through them, are the defining architectural determinants of both hygiene performance and operational efficiency in any meat processing facility.

Hygiene Requirements in Abattoirs

Hygiene in abattoir facilities is a multidimensional construct encompassing the physical condition of the built environment, the microbiological status of processing surfaces and equipment, the availability and quality of utilities such as water and drainage, and the effectiveness of waste and effluent management systems. The Codex Alimentarius Commission's Recommended Code of Hygienic Practice for Meat (CAC/RCP 58-2005) establishes the international benchmark for hygiene

in meat processing, prescribing requirements for the separation of clean and dirty operations to prevent cross-contamination, ante-mortem and post- mortem inspection protocols, temperature control throughout the processing chain, and potable water supply standards (CAC, 2005). These requirements carry direct architectural implications: they can only be met if the physical design of the facility provides the spatial, material, and engineering infrastructure necessary for their implementation. Water supply is among the most critical architectural hygiene provisions in an abattoir. The WHO (1983) stipulates that adequate potable water at sufficient pressure is essential at all stages of slaughter and processing. Hot water at not less than 82 degrees Celsius must be available for equipment and tool sterilisation, while separate supply lines for potable and non-potable water are required to prevent cross-contamination (Agriculture Institute, 2026). Drainage systems must rapidly evacuate blood, wash water, and processing effluent from all operational areas, with floor gradients of at minimum 20mm per metre sloping toward appropriately sized drains (Thanappan, 2022). Failure to meet these drainage standards is directly associated with the accumulation of organic matter on processing floors, which serves as a substrate for microbial proliferation and a source of carcass contamination (Hossain et al., 2025).

Ventilation represents another critical hygiene-related architectural requirement. Adequate ventilation must be provided in all processing areas to prevent the excessive accumulation of heat, steam, condensation, odours, and airborne contaminants, all of which promote microbial growth and compromise processing hygiene (Thanappan, 2022; ButcherSA, 2023). A well-designed ventilation system creates positive air pressure in clean product areas and negative pressure in raw and dirty zones, establishing a directional airflow that prevents contamination from moving from unclean to clean areas (Agriculture.Institute, 2026). Lighting requirements are equally important: inadequate lighting creates shadows where contamination can evade detection during inspection, increases the risk of worker accidents, and reduces the accuracy of ante-mortem and post-mortem examination (Agriculture Institute, 2026).

Despite these well-established requirements, empirical evidence from Nigeria consistently documents their widespread non-attainment. Adeyemi and Oyedele (2022) found that fewer than half of abattoir workers in Abakaliki, Ebonyi State, reported washing hands before and after handling meat — a direct consequence of the absence of handwashing infrastructure. A comprehensive scoping review of slaughterhouse hygiene practices in PLOS ONE documented consistent evidence of suboptimal hygiene practices attributable to deficient facility infrastructure across fourteen studies, with Nigeria accounting for one-third of included studies (Hossain et al., 2025). Uzoigwe et al. (2021) documented bacterial contamination of beef in slaughterhouses in the Owerri zone of Imo State, directly relevant to the present study's context. The pathogenic consequences include contamination with Escherichia coli, Salmonella, and Staphylococcus species, documented across sub-Saharan African abattoirs characterised by poor design and inadequate hygiene infrastructure (Ovuru et al., 2024).

Operational Efficiency in Meat Processing Facilities

Operational efficiency in abattoir facilities refers to the capacity of the facility to process animals and produce safe, quality meat products at the intended throughput rate, with minimal waste of time, labour, water, energy, and material resources, and without compromising hygiene standards or animal welfare. The spatial organisation of the facility — the layout of functional areas, the routing of personnel and product flows, and the provision of appropriate equipment and services — is the primary determinant of operational efficiency in a meat processing context (Agriculture Institute, 2026; Shija et al., 2020). The principle of unidirectional or one-way flow is the single most important spatial organising concept for operational efficiency in abattoir design. This principle holds that animals and meat products must move in one continuous, forward direction through the facility — from live animal reception through lairage, stunning, slaughter, dressing, inspection, chilling, and dispatch — with no backtracking, cross-movement, or intersection between clean and dirty product streams

(Agriculture.Institute, 2026; FAO, 1991). Departures from this principle create operational bottlenecks, increase the risk of cross-contamination, slow throughput, and create confusion among workers about hygienic boundaries (Akinro et al., 2018).

Lairage design is a critical determinant of operational efficiency, with direct implications for both animal welfare and meat quality. Grandin (2021), the internationally recognised authority on animal handling and welfare in meat processing, emphasises that well-designed lairage areas — incorporating curved races that exploit animals' natural tendency to move in circles, non-slip flooring, adequate shade and water provision, and calm, low-stress handling environments — significantly reduce the physiological stress experienced by animals before slaughter. This stress reduction directly improves meat quality, as elevated pre-slaughter stress hormones are associated with dark, firm, and dry (DFD) meat defects that reduce shelf life and commercial value (Miranda-de la Lama et al., 2019). The design of lairage areas is therefore simultaneously a welfare, quality, and commercial efficiency consideration.

Cold chain infrastructure — comprising chilling rooms, cold storage facilities, and refrigerated dispatch areas — is essential for maintaining operational efficiency in the post- slaughter phase. The absence of refrigeration in the majority of Nigerian abattoirs means that meat produced at these facilities has an extremely limited shelf life, resulting in significant post- harvest losses and driving the persistence of unhygienic informal meat retail practices (Akinro et al., 2018; Adeyemi & Oyedele, 2022). For the Ngor Okpala context, integration of even basic chilling infrastructure into the facility design represents a transformative improvement in operational and commercial efficiency.

Architectural Design Considerations for Abattoirs

The architectural design of an abattoir is a complex, multi-system design problem that demands the integration of spatial planning, structural engineering, environmental engineering, materials science, and regulatory compliance into a coherent, functional built form. Thanappan (2022) identifies the following as the core architectural design parameters for any abattoir: site selection and orientation; functional zoning and spatial organisation; structural system and building envelope; drainage and effluent management; water supply systems; ventilation and lighting design; materials selection; and personnel hygiene facilities. Each of these parameters carries direct implications for both hygiene performance and operational efficiency.

Site selection is the foundational architectural decision for any abattoir project. The FAO (1991) specifies that abattoir sites must be accessible from permanent roads; situated downwind and at an appropriate distance from residential areas to prevent odour and noise nuisance; provided with adequate water supply meeting potable water standards; and capable of accommodating appropriate effluent treatment and waste disposal systems without risk to water bodies or surrounding land. Shija et al. (2020), in a study of slaughterhouse spatial planning in East Africa, identified site selection as the most consequential and irreversible architectural decision in abattoir development, noting that poorly sited facilities cannot be adequately remediated through operational interventions alone.

Functional zoning is the architectural strategy of allocating distinct, spatially separated areas within the abattoir to different operational functions, with the explicit purpose of preventing cross-contamination between dirty operations (animal reception, lairage, stunning, bleeding, and initial dressing) and clean operations (carcass processing, inspection, chilling, and dispatch). This clean-dirty separation is mandated by both the FAO (1991) and the Codex Alimentarius Commission (CAC, 2005) as the primary spatial mechanism for hygiene control in meat processing. Architecture gives effect to this requirement through physical barriers, dedicated entry and exit points, separate ventilation systems maintaining appropriate pressure differentials, and clearly delineated personnel circulation routes with handwashing and gowning stations at zone boundaries (Agriculture.Institute, 2026; ButcherSA, 2023).

Materials selection for abattoir surfaces is a critical architectural hygiene consideration. The NSF/ANSI/3-A 14159-1-2024 standard sets minimum requirements for materials used in meat and poultry processing environments, requiring materials that resist high-pressure cleaning, humid environments, chemical sanitisers, and temperature extremes without cracking, chipping, or becoming porous (NSF/ANSI, 2024). For floor surfaces, non-porous, impervious materials with adequate traction for wet conditions are required, pitched at the prescribed gradient toward drainage outlets. Wall surfaces to a minimum height of two metres must be smooth, impervious, and light-coloured to facilitate inspection of cleanliness, while ceiling materials must resist moisture accumulation and condensation (Thanappan, 2022).

Drainage engineering is perhaps the most technically demanding architectural system in an abattoir, given the large volumes of blood, wash water, and organic effluent generated in processing operations. The Agriculture Institute (2026) specifies that the FAO recommends one drain for every 18 square metres of floor space in slaughtering areas and one drain for every 46 square metres in processing areas. All floors must be sloped toward the drains to ensure rapid runoff, with drains correctly located, trapped, and vented to prevent backflow and odour. Slot or trench drains are recommended in slaughter halls, while point drains work well for localized drainage in processing rooms (Agriculture Institute, 2026; Thanappan, 2022).

Sustainable Design Strategies in Meat Processing Facilities

The concept of sustainability in abattoir design encompasses environmental, economic, and social dimensions of particular relevance in the rural Nigerian context. Abattoir waste streams — including solid wastes such as condemned offal, hides, horns, and hooves; liquid effluents comprising blood, wash water, and gut contents; and gaseous emissions including ammonia and hydrogen sulphide — have the potential to cause severe pollution of surface water, groundwater, soil, and air if not managed through appropriately designed treatment systems (Ovuru et al., 2024; Akinro et al., 2018). Contemporary research increasingly advocates for the circular economy approach to abattoir waste, whereby solid biological waste is converted into value-added by-products such as blood meal, bone meal, hide products, and biogas, rather than being disposed of as waste (Chukwu et al., 2019; Frontiers in Sustainable Food Systems, 2024).

Biogas recovery from anaerobic digestion of abattoir effluent represents a growing area of sustainable design practice for meat processing facilities. Studies from African abattoir contexts have demonstrated the technical and economic viability of small-scale biogas installations for abattoir effluent treatment, capable of generating sufficient energy to meet a portion of the facility's hot water and electricity needs (Chukwu et al., 2019; Frontiers in Sustainable Food Systems, 2024). In the Ngor Okpala context, where electricity supply is unreliable and energy costs are a significant operational burden, biogas recovery from effluent treatment represents a contextually appropriate and economically viable sustainability strategy.

Passive design strategies offer significant potential for reducing the energy consumption and operating costs of abattoir facilities in tropical climates such as that of southeastern Nigeria. These include building orientation to harness prevailing winds for natural ventilation of lairage and ante-mortem areas; the use of deep overhanging roof eaves to shade processing areas and reduce solar heat gain; the incorporation of high-level louvred openings for cross-ventilation; and the use of locally sourced, thermally massive materials for external walls (ButcherSA, 2023; Thanappan, 2022). These passive strategies, when integrated with appropriate active ventilation systems in critical processing zones, can substantially reduce the reliance on mechanical cooling and electrical ventilation, lowering both operational costs and carbon emissions — a consideration of particular importance in a rural Nigerian context characterised by unreliable electricity supply.

3. MATERIALS AND METHODS

Research Design

This study adopts a qualitative, design-based research methodology, which is recognised in the architectural research literature as an appropriate and rigorous approach for investigations that seek to generate knowledge through the process and products of design (Groat & Wang, 2013). Design-based research in architecture operates on the premise that the act of designing — conceptualising, analysing, proposing, and evaluating built form solutions — is itself a valid and productive mode of knowledge generation, capable of producing insights that are not accessible through purely empirical or theoretical research methods alone (Cahyono et al., 2021; Creswell & Creswell, 2018). This approach is particularly appropriate for the present study, which seeks to investigate architectural strategies not merely as abstract principles but as concrete, contextually applied design responses to the documented hygiene and operational challenges of abattoir facilities in Ngor Okpala.

The study is structured as a single embedded case study, employing the proposed Ngor Okpala Meat Processing Facility as the primary case through which the research questions are examined. Yin (2018) establishes that the single case study design is appropriate when the case represents a critical, unique, or revelatory instance that illuminates a broader phenomenon of theoretical or practical significance. In this study, the Ngor Okpala Abattoir functions as both the subject of design investigation and the vehicle through which transferable architectural strategies for rural Nigerian abattoir design are identified, evaluated, and demonstrated.

Study Area

Ngor Okpala is a local government area located in Imo State, southeastern Nigeria. The area is predominantly rural in character, with an economy anchored in smallholder agriculture, livestock rearing, and local trade. Its population engages significantly in the keeping and trading of cattle, goats, sheep, and pigs, generating a sustained demand for local meat processing infrastructure. Currently, the area lacks any purpose-designed, hygienically compliant abattoir facility. Slaughter activities are conducted informally in open-air settings or makeshift enclosures, under conditions that preclude any meaningful compliance with the hygiene and operational standards prescribed by the FAO (1991) or the Codex Alimentarius Commission (CAC, 2005).

The climatic context of Ngor Okpala — characterised by a humid tropical climate with a distinct wet season (April to October) and a shorter dry season, mean annual temperatures of approximately 26 to 30 degrees Celsius, and high relative humidity throughout the year — presents specific architectural design challenges for abattoir facilities, particularly in relation to condensation control, natural ventilation, and the management of biological effluent during heavy rainfall periods. These climatic conditions have been incorporated into the design response developed and evaluated in this study.

Data Sources

Data for this study were drawn from three complementary sources. Primary data were derived from the architectural design process itself, including spatial analysis, design drawings, design rationale documentation, and site analysis of the proposed Ngor Okpala Abattoir. Secondary data were obtained through a comprehensive review of peer-reviewed journal articles, international design guidelines, regulatory standards, and technical manuals relevant to abattoir design, hygiene, and operational efficiency. Key secondary sources include FAO (1991), CAC (2005), Thanappan (2022), Ovuru et al. (2024), Hossain et al. (2025), and Uzoigwe et al. (2021). Tertiary data were obtained through a review of comparable design precedents from similar abattoir projects in developing country contexts documented in the literature (Agriculture Institute, 2026; Shija et al., 2020).

Design Evaluation Criteria

The design strategies developed for the proposed Ngor Okpala Abattoir were evaluated against a set of evidence-based criteria derived from the international literature and regulatory standards. These criteria encompass the following specific indicators: functional zone separation between clean and dirty operations (FAO, 1991; CAC, 2005); unidirectional process flow without cross-contamination risk (Agriculture.Institute, 2026); adequacy of drainage systems and floor gradients (Thanappan, 2022; Agriculture Institute, 2026); hot water provision at minimum 82°C (Agriculture.Institute, 2026); ventilation effectiveness and pressure differential between zones (ButcherSA, 2023; Agriculture Institute, 2026); lighting adequacy in inspection areas (Agriculture.Institute, 2026); hygienic material compliance for surfaces (NSF/ANSI, 2024; Thanappan, 2022); provision of personnel hygiene facilities (WHO, 1983; Thanappan, 2022); lairage design for animal welfare and operational flow (Grandin, 2021; FAO, 1991); and integration of waste and effluent management systems (Ovuru et al., 2024; Chukwu et al., 2019).

Design Development Process

The design development process for the proposed Ngor Okpala Abattoir followed a systematic evidence-informed sequence comprising five iterative stages. The first stage involved a comprehensive review of the literature and regulatory standards to establish the design brief and performance requirements. The second stage comprised site analysis, encompassing topographical, climatic, accessibility, and infrastructural assessment of the proposed site in Ngor Okpala. The third stage involved the development of spatial programming and functional zoning, establishing the required spaces, their dimensional standards, and their spatial relationships based on international abattoir design guidelines (FAO, 1991; Thanappan, 2022; Shija et al., 2020). The fourth stage comprised the generation and development of design proposals — including site layout, floor plans, sections, elevations, and engineering systems drawings — integrating the identified architectural strategies for hygiene and operational efficiency. The fifth and final stage involved the systematic evaluation of the developed design against the established criteria, identifying areas of compliance and implications for facility performance.

4. RESULTS AND DISCUSSION

Hygiene Challenges in Conventional Abattoirs in Nigeria

The review of literature and documentation of existing abattoir conditions in Nigeria reveals a consistent and interconnected set of hygiene challenges that collectively constitute a systemic failure of meat processing infrastructure across the country. These challenges are discussed below with particular reference to conditions documented in southeastern Nigeria and Imo State.

Absence of Clean and Dirty Zone Separation

The most fundamental and consequential hygiene failure in conventional Nigerian abattoirs is the absence of functional separation between clean and dirty operational zones. International standards require strict physical separation between areas where live animals are handled (dirty zone) and areas where dressed carcasses are processed and inspected (clean zone), with the explicit purpose of preventing cross-contamination of processed meat with animal waste, blood, and enteric pathogens (FAO, 1991; CAC, 2005). In the majority of Nigerian informal abattoirs, slaughter, dressing, and meat handling take place in the same undifferentiated space, without any physical barrier, directional flow control, or hygiene transition protocol between dirty and clean operations (Ovuru et al., 2024; Akinro et al., 2018). This condition is the primary architectural driver of carcass contamination with pathogens including Salmonella, Escherichia coli, and Staphylococcus documented in the Owerri zone of Imo State by Uzoigwe et al. (2021).

Inadequate Water Supply and Sanitation Infrastructure

Potable water supply at adequate pressure and volume is a non-negotiable requirement for hygienic meat processing. In most Nigerian informal abattoirs, consistent potable water supply is absent or intermittent, forcing workers to use untreated surface water or to operate without adequate cleaning facilities (Hossain et al., 2025; Adeyemi & Oyedele, 2022). Dahiru et al. (2025), in their assessment of abattoir workers in Bauchi State, found significant gaps in knowledge of occupational hygiene practices attributable directly to inadequate sanitary infrastructure provision. The absence of hot water sterilisation systems means that knives, cleavers, and processing equipment are frequently used across multiple carcasses without adequate decontamination, creating conditions for the systematic spread of pathogenic contamination throughout a processing session (Agriculture.Institute, 2026).

Deficient Drainage and Waste Management Systems

Adequate drainage is essential for the rapid and hygienic removal of blood, wash water, and organic effluent from processing floors. In conventional Nigerian abattoirs, the absence of properly graded floors, purpose-designed drainage channels, and connected waste management systems means that blood and effluent accumulate on processing surfaces, creating conditions simultaneously hazardous to workers through slip-and-fall accidents and highly conducive to microbial proliferation (Thanappan, 2022; Akinro et al., 2018). Studies from southeastern Nigeria have documented the near-total absence of sanitary waste disposal practices in abattoir facilities, attributing this directly to the lack of waste management infrastructure (Adeyemi & Oyedele, 2022). This practice has been identified as a systemic public health problem with significant implications for surrounding communities, including groundwater contamination and proliferation of disease vectors (Ovuru et al., 2024; Chukwu et al., 2019).

Inadequate Ventilation and Lighting

Poor ventilation in abattoir processing areas promotes the accumulation of heat, steam, and moisture that creates favourable conditions for microbial growth on carcasses and processing surfaces. Condensation on ceilings and walls — a direct consequence of inadequate ventilation design — is a significant source of carcass contamination, as condensate droplets containing microorganisms drip onto exposed meat surfaces (ButcherSA, 2023; Agriculture Institute, 2026). Deficient artificial and natural lighting further compromises hygiene by creating shadowed areas where contamination evades detection during inspection, reducing the accuracy of ante-mortem and post-mortem examination, and increasing the probability that condemned meat enters the food supply chain (Agriculture.Institute, 2026; Hossain et al., 2025).

Operational Inefficiencies in Existing Facilities

The operational inefficiencies documented in conventional Nigerian abattoir facilities are closely interrelated with the hygiene challenges described above and share the same root cause: the absence of evidence-based architectural design. The absence of unidirectional process flow is the most operationally consequential design failure. Without a clear directional sequence from animal reception to meat dispatch, workers and products are compelled to move back and forth across the facility, creating congestion, confusion about hygienic boundaries, and significant time losses that reduce throughput capacity (Agriculture Institute, 2026; Akinro et al., 2018). Inadequate lairage provision means that animals arrive at the point of slaughter in a stressed and often fatigued condition, adversely affecting both meat quality and the safety of slaughter workers (Grandin, 2021; Miranda-de la Lama et al., 2019). The near-total absence of cold chain infrastructure in Nigerian informal abattoirs forces rapid and unhygienic meat distribution immediately after slaughter, precluding quality management and extending the meat supply chain under ambient tropical temperatures that accelerate spoilage (Adeyemi & Oyedele, 2022; Akinro et al., 2018). Overcrowding of functional spaces due to inadequate spatial planning further compounds these

inefficiencies, creating worker safety hazards and preventing the effective separation of clean and dirty operations (Thanappan, 2022; Shija et al., 2020).

Proposed Architectural Design Strategies for Ngor Okpala Abattoir

In response to the identified hygiene challenges and operational inefficiencies, the proposed design for the Ngor Okpala Meat Processing Facility integrates six evidence-based architectural strategies, described below with reference to their application in the proposed design and their empirical and regulatory grounding.

Strategy 1: Functional Zone Separation

The proposed design establishes a clear and unambiguous spatial separation between dirty and clean operational zones through the use of physical barriers, controlled access points, and separate building wings for ante-mortem and post-mortem operations. The dirty zone — encompassing the lairage, ante-mortem inspection facility, stunning bay, bleeding channel, and scalding area for pigs — is located at the windward side of the site and separated from the clean zone by a dedicated dressing area that functions as a hygiene transition space. The clean zone — comprising the carcass processing hall, post-mortem inspection area, chilling room, and dispatch bay — is located at the leeward side, ensuring that prevailing wind does not carry airborne contaminants from dirty to clean areas (FAO, 1991; CAC, 2005; Agriculture Institute, 2026). Personnel handwashing and gowning stations are positioned at all zone boundaries (Agriculture.Institute, 2026; NSF/ANSI, 2024).

The spatial organisation of the proposed facility is structured around a strict linear, unidirectional flow sequence that routes animals and products from lairage through ante-mortem inspection, stunning, slaughter, bleeding, scalding where applicable, dressing, post-mortem inspection, chilling, and dispatch without any backtracking or cross-contamination risk (Agriculture.Institute, 2026). The plan layout achieves this through a linear building arrangement in which each functional space succeeds the previous in the processing sequence, with dedicated, directionally controlled access routes for animals, carcasses, personnel, and waste that do not intersect (Shija et al., 2020). Overhead rail systems in the dressing and processing halls further enforce unidirectionality by suspending carcasses above floor level throughout the clean zone, preventing contact between processed meat and processing floor surfaces (Thanappan, 2022).

Strategy 2: Hygienic Material Selection

All internal surfaces of the proposed facility — walls, floors, ceilings, and fixed fittings - have been specified in compliance with the requirements of NSF/ANSI/3-A 14159-1-2024 for meat and poultry processing environments (NSF/ANSI, 2024). Floor surfaces throughout all wet processing areas are specified in non-porous, impervious, acid-resistant ceramic tiles with a textured finish providing traction under wet conditions, pitched at a gradient of not less than 20mm per metre toward drainage outlets (Thanappan, 2022). Wall surfaces to a minimum height of 2.4 metres are clad in smooth, light-coloured, impervious glazed tiles that resist chemical sanitisers and facilitate visual inspection of cleanliness. Stainless steel — grade 304 or higher — has been specified for all fixed equipment, work surfaces, drainage channels, and door frames in processing areas (NSF/ANSI, 2024). Ceilings in processing areas are specified in smooth, moisture-resistant, cleanable panels at a minimum height of 3.0 metres to reduce condensation risk and facilitate adequate ventilation (Thanappan, 2022).

Strategy 3: Engineered Drainage Systems

A comprehensive drainage engineering strategy has been integrated into the proposed design, addressing floor gradients, drain sizing, channel design, and effluent routing. All processing area floors are graded to purpose-designed stainless steel slot drains — providing.

Strategy 4: Unidirectional Process Flow Layout

One drainage outlet per 18 square metres in slaughtering areas and one per 46 square metres in processing areas, in compliance with FAO (1991) and Agriculture Institute (2026) specifications. All drains are designed with traps and vents to prevent backflow and odour, and are specified for easy removal and cleaning to prevent blockages and associated contamination (Agriculture.Institute, 2026; Thanappan, 2022). A dedicated effluent treatment facility — incorporating a primary screening and sedimentation tank, an anaerobic digestion chamber for biogas recovery, and a final polishing pond — has been incorporated into the site design, in compliance with Nigerian environmental regulations and the sustainability recommendations of Ovuru et al. (2024) and Chukwu et al. (2019).

Strategy 5: Climate-Responsive Ventilation and Lighting Design

The ventilation strategy for the proposed Ngor Okpala facility integrates passive and active design approaches calibrated to the humid tropical climate of southeastern Nigeria. The lairage and ante-mortem areas are designed as largely open, roofed structures with continuous high-level louvred openings on all sides to maximise natural cross-ventilation, reducing heat stress on animals and lowering the humidity load on the building's active ventilation systems (Grandin, 2021). The processing hall and clean zone areas are provided with a mechanical ventilation system that maintains positive air pressure in clean zones and negative pressure in dirty zones, ensuring a directional airflow from clean to dirty areas that prevents airborne contamination migration (Agriculture Institute, 2026; ButcherSA, 2023). All ventilation openings are screened with fly-proof mesh to prevent insect ingress — a critical requirement in the tropical Nigerian context (Thanappan, 2022). Lighting provision complies with Agriculture Institute (2026) minimum standards in all inspection areas, with daylight supplemented by LED task lighting at post-mortem inspection stations.

Strategy 6: Integrated Waste and Effluent Management

An integrated solid and liquid waste management system has been incorporated into the proposed design, addressing the collection, separation, treatment, and disposal of all waste streams generated by abattoir operations. Solid waste — including condemned offal, hides and skins, horns, hooves, and general processing waste — is routed to a dedicated by-product processing and solid waste holding area physically separated from all clean processing areas. Biogas recovery from anaerobic digestion of abattoir effluent has been incorporated as a sustainable energy option, consistent with recent studies demonstrating the viability of small- scale biogas installations in African abattoir contexts (Chukwu et al., 2019; Frontiers in Sustainable Food Systems, 2024). Liquid effluent is directed to the three-stage treatment facility described above, with treated effluent meeting minimum quality standards before discharge (Ovuru et al., 2024).

Implications for Facility Performance

The six architectural strategies described above, when implemented collectively in the proposed Ngor Okpala Abattoir design, are assessed to produce substantial improvements in both hygiene performance and operational efficiency relative to the conventional informal facilities they replace. In relation to hygiene, the functional zone separation and unidirectional flow strategies directly address the most consequential hygiene failure of conventional Nigerian abattoirs — the absence of clean/dirty zone separation — by making cross-contamination structurally impossible within the facility (FAO, 1991; CAC, 2005). The hygienic material specifications and engineered drainage systems reduce the accumulation of organic matter on processing surfaces, lowering the microbial load throughout the facility (Thanappan, 2022; NSF/ANSI, 2024). The ventilation and lighting strategy improves the detectability of contamination during inspection and reduces condensation that promotes microbial growth (ButcherSA, 2023; Agriculture Institute, 2026).

In relation to operational efficiency, the unidirectional flow layout reduces processing time, worker movement, and operational congestion, while the purpose-designed lairage improves animal welfare and meat quality outcomes (Grandin,

2021; Miranda-de la Lama et al., 2019). The integration of even minimal chilling infrastructure fundamentally extends the shelf life of processed meat and opens commercial opportunities currently unavailable to informal abattoirs in the area (Akinro et al., 2018). The waste and effluent management system, beyond its direct environmental and public health benefits, removes a significant operational burden from the facility's workers and management, replacing ad hoc waste disposal with a structured and accountable protocol (Ovuru et al., 2024; Chukwu et al., 2019).

Discussion of Findings

The findings of this study confirm and extend the body of evidence that the hygiene and operational challenges of abattoir facilities in developing countries — Nigeria included — are fundamentally architectural in nature. While existing literature has extensively documented the consequences of abattoir hygiene failures from veterinary, public health, and food safety perspectives (Ovuru et al., 2024; Hossain et al., 2025; Dahiru et al., 2025), the present study's contribution lies in its demonstration that deliberate, evidence-based architectural design can serve as the primary intervention mechanism for addressing these failures at their root cause.

The six strategies identified and applied in the proposed Ngor Okpala design are well established in the international abattoir design literature and regulatory standards (FAO, 1991; Thanappan, 2022; Agriculture Institute, 2026). What this study contributes is its systematic integration into a contextually specific, implementable design response for the rural Nigerian setting — an integration that has been largely absent from both architectural practice and scholarly discourse in this country. The study thus validates the argument advanced by Groat and Wang (2013) and elaborated by Cahyono et al. (2021) that design-based research can generate contextually grounded, practically applicable knowledge that purely theoretical or empirical approaches cannot produce alone.

The significance of the Imo State context is particularly noteworthy. Uzoigwe et al. (2021) documented bacterial contamination of beef in slaughterhouses in the Owerri zone of Imo State, providing the most directly relevant local evidence base for the design interventions proposed in this study. The proposed Ngor Okpala Abattoir, if implemented as designed, would represent the first architecturally compliant, hygienically designed meat processing facility in the local government area and a significant model for similar interventions across Imo State. The findings further align with and amplify the recommendations of Ozoji (2021), who called for regulatory reform and private sector involvement in abattoir infrastructure development in Nigeria — both prerequisites for the realisation of architecturally designed facilities of the type proposed here.

5. CONCLUSION

This study has examined architectural design strategies for enhancing hygiene standards and operational efficiency in abattoir facilities, using the proposed Ngor Okpala Meat Processing Facility in Imo State, Nigeria, as a design-based case study. The study established that the hygiene and operational deficiencies characterising the vast majority of abattoir facilities in Nigeria – including the absence of functional zone separation, inadequate drainage and water supply, deficient ventilation and lighting, and the lack of integrated waste management systems - are primarily rooted in architectural and planning failures addressable through evidence-based design intervention.

Six core architectural strategies were identified, evaluated, and applied in the proposed Ngor Okpala Abattoir design: functional zone separation; unidirectional process flow; hygienic material selection; engineered drainage systems; climate-responsive ventilation and lighting; and integrated waste and effluent management. The proposed design demonstrates that these strategies, when applied collectively in an integrated and contextually responsive design framework, can substantially

improve hygiene compliance and operational performance in a rural Nigerian meat processing facility. The study contributes an original, evidence-based architectural design framework for abattoir development in rural southeastern Nigeria, grounded in international design standards (FAO, 1991; CAC, 2005; Thanappan, 2022) and calibrated to the specific environmental, economic, and infrastructural conditions of Ngor Okpala.

Based on the findings and conclusions of this study, the following recommendations are advanced:

i. Government agencies responsible for public health, urban development, and food safety regulation in Imo State should adopt the architectural design framework developed in this study as a model for the development of hygienically compliant abattoir facilities in Ngor Okpala and other rural local government areas in the state (Ozoji, 2021; Hossain et al., 2025).

ii. The Federal Ministry of Housing and Urban Development should develop and disseminate standardised architectural design briefs and minimum facility standards for rural abattoirs in Nigeria, drawing on the international guidelines of FAO (1991), WHO (1983), and Thanappan (2022), adapted to the climatic and infrastructural conditions of different geopolitical zones.

iii. Architects and built environment professionals in Nigeria are encouraged to engage proactively with the design of food processing infrastructure — including abattoirs, markets, and storage facilities — as a domain of professional practice with significant public health and food security implications, consistent with the expanded scope of architectural practice advocated by Cahyono et al. (2021) and Shija et al. (2020).

iv. Future research should expand upon the design-based methodology employed in this study to develop and evaluate abattoir design frameworks for other ecological zones and urban scales in Nigeria, addressing the design requirements of medium-scale urban abattoirs alongside the rural facilities examined here.

v. The integration of biogas recovery from abattoir effluent treatment as a sustainable energy strategy should be investigated further as a technically and economically viable option for reducing the operating costs and environmental footprint of meat processing facilities in rural Nigeria, in alignment with the sustainability recommendations of Chukwu et al. (2019) and Frontiers in Sustainable Food Systems (2024).

Contribution to Knowledge

This study makes four original contributions to the scholarly and professional literature. First, it provides the first architecture-centred, design-based analysis of abattoir facility development specifically in Ngor Okpala, Imo State, establishing a contextually grounded empirical and design evidence base where none previously existed. Second, it demonstrates the validity and productivity of design-based research methodology for investigating public health and food safety infrastructure in developing country architectural contexts (Groat & Wang, 2013; Cahyono et al., 2021). Third, it synthesises an integrated, six-strategy architectural framework for rural abattoir design that is simultaneously grounded in international standards and adapted to the specific conditions of southeastern Nigeria — a framework replicable across similar rural contexts in the sub-Saharan African region. Fourth, it contributes to the interdisciplinary literature at the intersection of architecture, public health, food science, and sustainable development, arguing for a more prominent role for the architectural profession in the design of food safety infrastructure across Nigeria and the developing world.

6. COMPETING INTERESTS

None to declare.

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