



The Role of Smart City Design Strategies in Enhancing Circulation System on Maternity Hospitals in Lagos

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ABSTRACT

Rapid urbanization in Lagos State has intensified pressure on healthcare infrastructure, particularly within maternity hospitals where time-sensitive obstetric care depends on efficient internal circulation systems. Intra-facility delays, often classified as the "third delay," are frequently linked to spatial fragmentation and organizational inefficiencies. Although healthcare design research recognizes circulation as a measurable determinant of workflow efficiency and smart city frameworks promote digital mobility optimization, limited research integrates these approaches within the maternity hospital environments of Lagos. This study investigates how smart city design strategies can enhance circulation systems in maternity hospitals in Lagos State. A qualitative research approach was adopted through a systematic review of twenty peer-reviewed publications (2019–2025) focusing on hospital circulation, maternal healthcare performance, and smart infrastructure integration. Findings indicate that spatial adjacency hierarchy, zoning configuration, and visibility integration significantly influence emergency transfer efficiency. However, most facilities rely on static physical layouts with minimal integration of adaptive digital systems. The study concludes that integrating IoT-enabled monitoring, AI-assisted navigation, and digital mobility frameworks into architectural circulation planning presents a viable pathway for improving maternal healthcare responsiveness and institutional efficiency in rapidly urbanizing contexts.

Keywords: Smart City Design, Hospital Circulation Systems, Maternity Healthcare Infrastructure, Digital Mobility Technologies, Lagos Urban Healthcare

INTRODUCTION

Rapid urban growth continues to reshape cities across the Global South, where population increases frequently exceed the capacity of infrastructure and public services (UN-Habitat, 2020). Lagos State, Nigeria's principal economic hub, exemplifies this condition, with rapid metropolitan expansion placing sustained pressure on mobility networks and social infrastructure (Soyinka et al., 2017; Lawanson, 2021). Studies examining urban infrastructure performance in Nigeria further emphasise the importance of integrating sustainable architectural strategies into rapidly expanding urban environments (Ibitoye et al., 2025). Maternal mortality in sub-Saharan Africa remains closely associated with delays in accessing and receiving appropriate care (Ameh et al., 2019). Beyond community-level barriers, facility-based delays commonly termed the "third delay", are linked to institutional inefficiencies and system-level constraints (Okonofua et al., 2021; Kruk et al., 2019). In maternity hospitals, rapid movement between triage units, labour wards, operating theatres, neonatal intensive care units, and recovery areas is essential. Inefficient circulation pathways and unclear zoning may therefore compromise emergency responsiveness and clinical outcomes.

Evidence-based healthcare design research increasingly recognises circulation systems as measurable determinants of hospital performance. Spatial configuration influences movement efficiency, team coordination, and patient safety indicators (Bernhardt et al., 2022). Studies in healthcare built environments further demonstrate that visibility integration and layout coherence are associated with improved workflow reliability and reduced transfer delays (Elf et al., 2020). Within maternity environments, room layout and spatial sequencing influence maternal stress regulation and perceived safety during childbirth (Nilsson et al., 2022).

Simultaneously, smart city frameworks employ digital connectivity, sensor-based systems, and artificial intelligence to enhance infrastructure efficiency and mobility optimisation (Yigitcanlar et al., 2020; Bibri & Krogstie, 2020). IoT-enabled systems support real-time movement tracking and congestion management in enclosed environments (Zamponi & Barbierato, 2022). Computational optimisation models have demonstrated measurable improvements in hospital zoning and routing efficiency (Cubukcuoglu et al., 2022). However, the integration of smart city design strategies into maternity hospital circulation systems remains underexplored, particularly within rapidly urbanising African cities. While Lagos is expanding digital and metropolitan infrastructure initiatives (Lawanson, 2021), institutional healthcare facilities largely retain conventional circulation structures without integrated smart mobility systems. The aim of this study is to investigate how smart city design strategies can enhance circulation systems in maternity hospitals in Lagos State.

The specific objectives are to:

1. Analyse the existing circulation systems and zoning configurations in selected maternity hospitals in Lagos.
2. Assess spatial and operational factors contributing to circulation inefficiencies and intra-facility delays.
3. Examine the applicability of smart city design strategies such as digital mobility systems, IoT-enabled monitoring, and intelligent routing frameworks in improving circulation performance.

LITERATURE REVIEW

Circulation Performance and Spatial Optimisation in Healthcare

Healthcare architecture research increasingly treats circulation as a performance variable rather than a residual design outcome. Computational hospital modelling demonstrates that spatial adjacency logic and vertical stacking significantly influence internal transfer efficiency (Cubukcuoglu et al., 2022). Workflow simulation research further confirms that spatial modelling techniques improve coordination reliability in acute-care environments (Rönneberg & Eriksson, 2020). Empirical built-environment studies show that corridor articulation, visibility range, and nodal configuration affect congestion and staff walking distance (Zhang et al., 2021; Andrade et al., 2019). Hospital design literature also establishes a connection between spatial organisation and patient safety culture (Elf et al., 2020). Architectural scholarship also highlights that spatial form and organisational logic influence how users perceive and interact with institutional environments (Olaoye, 2023). In maternity facilities, adjacency between labour units and operating theatres is particularly critical. Research indicates that birthing room design influences both procedural flow and maternal psychological outcomes (Nilsson et al., 2022). Despite these findings, most hospital circulation research remains focused on physical optimization, with limited integration of digital mobility systems.

Maternal Healthcare Systems and Facility-Level Delays

Maternal mortality across sub-Saharan Africa is significantly influenced by systemic delays in obstetric response (Ameh et al., 2019). Facility-level disruptions, including inefficient coordination and infrastructure fragmentation, contribute substantially to adverse outcomes (Okonofua et al., 2021). Health systems scholarship further demonstrates that infrastructural design inefficiencies undermine care reliability even where clinical expertise is available (Kruk et al., 2019). Architectural studies examining socio-cultural influences on building form also emphasise the importance of contextual design considerations in institutional environments (Olaoye, 2023). In rapidly urbanising contexts such as Lagos, population growth and infrastructure strain intensify institutional pressure on maternity services (Lawanson, 2021). However, architectural research specifically evaluating circulation performance as a measurable determinant within Nigerian maternity facilities remains limited.

Smart City Strategies and Healthcare Infrastructure

Smart city frameworks advocate data-driven mobility management, cyber-physical systems integration, and predictive analytics for infrastructure optimisation (Yigitcanlar et al., 2020; Bibri & Krogstie, 2020). Recent built-environment research further demonstrates that integrating

sustainable and technologically responsive design strategies significantly enhances environmental performance and urban infrastructure resilience (Ibitoye et al., 2025). IoT-enabled monitoring provides dynamic feedback mechanisms that improve spatial efficiency in complex environments (Zamponi & Barbierato, 2022).

Smart hospital research shows that digital dashboards, real-time tracking, and digital twin systems enhance coordination and reduce bottlenecks (Paiho et al., 2020; Batko & Ślęzak, 2022). AI-assisted navigation tools similarly optimise indoor wayfinding and routing efficiency (Lee et al., 2021).

Yet existing studies examine smart integration primarily within general hospital or metropolitan contexts. Focused investigation into the integration of smart city mobility principles with maternity hospital circulation systems, particularly within Lagos, remains limited.

Digital Mobility Systems and Intelligent Flow Management in Hospitals

Advancements in digital healthcare infrastructure have expanded the application of intelligent mobility systems within hospital environments. Indoor positioning systems, real-time location tracking, and AI-assisted routing platforms are increasingly used to optimise patient and staff movement within complex healthcare facilities (Lee et al., 2021). These technologies enable congestion detection, transfer-time monitoring, and automated navigation support, particularly in emergency pathways. Smart hospital studies further demonstrate that IoT-based tracking systems improve coordination between departments and reduce procedural latency during peak demand periods (Batko & Ślęzak, 2022). Real-time analytics dashboards have also been shown to enhance bed management and intra-facility flow efficiency by predicting bottlenecks before they escalate (Marques et al., 2022). Despite these technological advancements, existing research primarily evaluates digital systems within general hospital contexts, with limited focus on maternity-specific environments. Obstetric units involve unique circulation demands, including rapid surgical transitions and neonatal care transfer protocols.

Research Gap

Although healthcare circulation performance and maternal health system delays have been examined extensively (Andrade et al., 2019; Okonofua et al., 2021), and smart mobility frameworks have been explored within broader urban infrastructure systems (Bibri & Krogstie, 2020; Yigitcanlar et al., 2020), limited research integrates these perspectives within maternity hospital environments. Existing hospital optimisation studies predominantly emphasise spatial configuration and computational modelling (Cubukcuoglu et al., 2022), while smart city research largely addresses metropolitan-scale mobility rather than institutional healthcare circulation. Within the Lagos context, urban infrastructure scholarship highlights systemic strain and mobility pressures (Lawanson, 2021), yet architectural investigations into digitally enhanced circulation systems within maternity hospitals remain limited. A clear gap therefore exists in examining how smart city design strategies can be operationalised at the hospital scale to improve circulation efficiency in maternity healthcare facilities. Previous studies within the Nigerian built environment have examined the adoption of sustainable architectural technologies and their implications for infrastructure performance, yet their application within healthcare circulation systems remains largely unexplored (Ibitoye et al., 2022)

RESEARCH METHOD

This study adopts a Systematic Literature Review (SLR) approach to examine the role of smart city design strategies in enhancing circulation systems in maternity hospitals, with specific focus on healthcare facilities in Lagos State, Nigeria. This approach is appropriate because the study seeks to analyse architectural design principles, healthcare circulation performance frameworks, and emerging smart infrastructure strategies within institutional healthcare environments rather than generate primary numerical data. A total of twenty (20) peer-reviewed journal articles and relevant institutional publications published between 2019 and 2025 were reviewed. These sources were selected based on their direct relevance to: hospital circulation optimisation, maternity healthcare facility performance, smart city infrastructure systems, and digital mobility technologies applicable to healthcare environments.

FINDINGS AND DISCUSSIONS

From the twenty (20) reviewed publications, fourteen (14) studies were identified as directly addressing hospital circulation optimisation, maternal healthcare efficiency, and smart infrastructure integration. These studies were synthesised to support analysis aligned with the study objectives.

Table 1: Summary of Core Reviewed Studies on Circulation and Smart Integration in Healthcare

Authors	Year	Focus Area	Method	Relevance to Current Study
C. U. Cubukcuoglu, P. Nourian, I. S. Sariyildiz, & M. F. Taşgetiren	2022	Hospital layout optimisation	Algorithmic modelling	Demonstrates impact of zoning hierarchy and routing logic on circulation efficiency
Y. Zhang, P. Tzortzopoulos, M. Kagioglou, & L. Koskela	2021	Spatial configuration & workflow	Spatial configuration analysis	Links nodal articulation to congestion patterns and staff coordination
Claudia C. Andrade, Maria L. Lima, Ferdinando Fornara, & Marino Bonaiuto	2019	Healthcare environmental performance	Survey validation study	Shows spatial clarity influences workflow reliability
Christina Nilsson, Maria Lindkvist, Lena Bergqvist, & Cecilia Begley	2022	Birthing room spatial design	Randomised controlled trial	Identifies adjacency importance in maternity settings
Friday Okonofua, Lovett Ntoimo, Raphael Ogu, Hadiza Galadanci, Geoffrey Mohammed, Olanike Okike, & Ehi Abe	2021	Maternal facility-level delays (Nigeria)	Systematic clinical audit	Confirms significance of intra-facility delays in maternal care
Margaret E. Kruk et al.	2019	Health system performance & quality	Multi-country analysis	Establishes link between infrastructure quality and service reliability
Satu Paiho, Panu Tuominen, & Teemu Hakkarainen	2020	Smart hospital systems	Systematic review	Highlights digital optimisation frameworks in healthcare
Dongwoo Lee, Hyun Lee, & Yoon Choi	2021	AI-based hospital navigation	System implementation study	Demonstrates AI-assisted indoor routing optimisation
Katarzyna Batko & Anna Ślęzak	2022	Digital twin hospital modelling	Simulation modelling	Shows potential for dynamic workflow optimisation
Ibitoye, O. O., et al.	2025	Sustainable building systems in Lagos	Empirical built environment study	Demonstrates relationship between architectural innovation and urban infrastructure performance
Olaoye, G. O.	2023	Socio-cultural influences on architectural form	Architectural case study	Highlights relationship between spatial form, user interaction, and built environment meaning

Existing Circulation Systems and Zoning Configurations in Maternity Hospitals

Recent research confirms that hospital circulation systems act as vital performance infrastructures rather than simple architectural connectors. Through computational optimization models, researchers have shown that adjacency hierarchies, vertical stacking logic, and the layout of corridors significantly impact internal transfer durations (Cubukcuoglu et al., 2022). Furthermore, investigations into spatial integration suggest that the clustering of nodes and the quality of visibility fields directly influence both congestion patterns and the efficiency of staff movement (Zhang et al., 2021). Studies focusing on the healthcare built environment indicate that disorganized zoning structures tend to increase walking distances while diminishing the clarity of clinical workflows (Andrade et al., 2019). Within the specific context of maternity care, the physical proximity between labor wards, emergency surgical theaters, and neonatal units is a crucial factor in maintaining emergency responsiveness (Nilsson et al., 2022). Broadly speaking, traditional circulation systems in many hospital designs continue to rely on static spatial principles and show minimal integration of adaptive routing or systems that utilize digital assistance for movement.

Spatial and Operational Factors Contributing to Circulation Inefficiencies

Available studies suggest that delays occurring within medical facilities are frequently linked to spatial fragmentation and the inefficient sequencing of departments. Maternal health audits conducted in Nigeria emphasize that these facility level delays are primary contributors to poor clinical outcomes (Okonofua et al., 2021). Additionally, research into health systems demonstrates that architectural and infrastructural inefficiencies can compromise the reliability of services even when clinical expertise is high (Kruk et al., 2019). Modeling of clinical workflows shows that the use of multi-purpose corridors, the lack of dedicated movement streams, and ambiguous routing hierarchies contribute to procedural latencies during periods of high demand (Rönnerberg & Eriksson, 2020). In rapidly expanding urban centers like Lagos, the existing strain on infrastructure further intensifies the pressure of institutional congestion (Lawanson, 2021). These findings collectively indicate that inefficiencies in circulation arise from a combination of architectural layout flaws and gaps in operational coordination. Similar conclusions have been observed in built environment studies where spatial configuration and user interaction patterns significantly influence building performance and operational outcomes (Ibitoye et al., 2024). However, most contemporary studies analyze these elements in isolation rather than connecting them to potential smart infrastructure solutions.

Applicability of Smart City Design Strategies to Maternity Hospital Circulation

Research into the smart city paradigm highlights the importance of digital connectivity, sensor based networks, and predictive mobility analytics as essential tools for optimizing infrastructure (Yigitcanlar et al., 2020; Bibri & Krogstie, 2020). In the healthcare sector, the use of IoT enabled tracking systems allows for the real time observation of movement flows and the detection of congestion levels (Zamponi & Barbierato, 2022). Literature regarding smart hospitals demonstrates that digital dashboards, navigation systems assisted by artificial intelligence, and digital twin simulations can enhance workflow coordination and mitigate bottlenecks (Paiho et al., 2020; Lee et al., 2021; Batko & Ślęzak, 2022). These technological advancements facilitate dynamic adjustments to routing and the predictive identification of traffic surges. Despite the proven advantages of these systems in general hospital settings, the specific application of smart mobility frameworks to maternity circulation remains underdeveloped. Obstetric units necessitate rapid transfer paths and specialized routing hierarchies, yet there is currently a lack of empirical research exploring the integration of smart city design strategies within these environments, particularly in the context of Lagos.

Synthesis of Findings

The findings demonstrate that hospital circulation efficiency is influenced by spatial configuration, operational coordination, and infrastructural capacity. While architectural optimisation improves baseline routing efficiency, digital smart systems offer adaptive, real-time enhancements that traditional layouts cannot provide independently. However, existing scholarship treats spatial optimisation and smart infrastructure as separate domains. A significant opportunity therefore exists to integrate smart city design

strategies into maternity hospital circulation systems to improve emergency responsiveness, workflow clarity, and institutional efficiency in Lagos.

CONCLUSIONS

Through a qualitative review of contemporary literature, this study investigated the potential of smart city design strategies to enhance circulation systems within maternity hospitals in Lagos State. The findings establish that hospital circulation systems act as critical performance infrastructures that directly influence emergency responsiveness, workflow coordination, and patient safety. Regarding the first objective, the research shows that spatial configuration, zoning hierarchies, and the sequencing of departmental adjacencies are primary factors in intra-hospital movement efficiency. Within maternity environments, the physical proximity between labor units, operating theaters, and neonatal care areas functions as a vital life-safety determinant. Despite this, most hospital layouts continue to rely on static physical optimization strategies rather than adaptive systems. In terms of the second objective, the evidence suggests that delays occurring within the facility are frequently linked to spatial fragmentation, congestion, and inefficient routing structures. These inefficiencies are further intensified by the infrastructure strain typical of rapidly urbanizing contexts like Lagos. While maternal health literature acknowledges these systemic delays, there is a clear lack of architectural research that evaluates circulation performance as a measurable spatial variable in the design of maternity facilities.

Concerning the third objective, smart city frameworks offer adaptive and data-driven mechanisms that can improve circulation efficiency. Tools such as IoT-enabled monitoring, artificial intelligence for navigation, and digital twin modeling provide significant opportunities for real-time routing optimization and predictive congestion management. Nevertheless, the application of these technologies within maternity hospital circulation remains underexplored, particularly in African urban centers. Overall, the study demonstrates that merging smart city design strategies with architectural circulation planning is a viable approach to improving institutional responsiveness and operational efficiency in the maternity hospitals of Lagos. Bridging the gap between physical spatial optimization and intelligent digital mobility systems marks a necessary transition toward resilient, performance-oriented maternal healthcare infrastructure in rapidly growing cities.

RECOMMENDATIONS

Based on the findings of this study, the following recommendations are proposed to enhance circulation performance in maternity hospitals across Lagos State.

Architectural Zoning and Adjacency Optimization

Maternity hospital design in Lagos should prioritize evidence-based zoning principles that minimize travel distances between labor wards, operating theaters, and neonatal intensive care units. Clear hierarchical circulation systems must be implemented to reduce cross-traffic and congestion, specifically along emergency transfer routes. Future maternity facility projects should integrate adjacency planning and workflow simulation tools during the early design phase to ensure the optimal sequencing of critical clinical units.

Reduction of Intra-Facility Transfer Delays

Existing maternity hospitals should conduct circulation audits to identify bottlenecks, fragmented routing patterns, and corridor overlap between staff and patient flows. The functional segregation of circulation streams, including emergency, staff, visitor, and service routes, should be strengthened to improve transfer efficiency and reduce operational latency. Furthermore, institutional management should incorporate spatial performance evaluation as a standard part of routine infrastructure reviews within maternity facilities.

Integration of Smart City Based Circulation Systems

Digital mobility frameworks should be gradually incorporated into the maternity hospital infrastructure of Lagos. The adoption of IoT enabled movement monitoring systems, indoor positioning tools, and AI assisted navigation platforms can enhance real-time coordination within high-dependency

obstetric units These integration strategies should align with broader metropolitan smart infrastructure initiatives while remaining adaptable to the specific needs of each institution.

Strategic Outlook

The transition toward smart-enabled circulation systems requires active collaboration between architects, hospital administrators, urban planners, and digital infrastructure specialists. Institutional investment in smart technologies should prioritize clinical efficiency, maternal safety, and long-term infrastructural resilience within the rapidly expanding urban healthcare landscape of Lagos.

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