

The Post-Pandemic Hospital: A Systematic Review of Architectural and Spatial Intervention Literature (2020–2026)

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Abstract

The COVID-19 pandemic exposed profound structural vulnerabilities in hospital architecture globally, overwhelming fixed-capacity intensive care units, collapsing infection separation systems, and demanding spatial adaptations for which the built environment was fundamentally unprepared. In the years since the pandemic's onset, a substantial body of peer-reviewed literature has emerged documenting architectural and spatial responses to this unprecedented challenge, yet it remains fragmented across disciplines and geographies, without the systematic synthesis required to guide evidence-based practice and policy. This paper aims to conduct a PRISMA 2020-guided systematic review of all peer-reviewed architectural and spatial intervention literature published between January 2020 and April 2026, addressing pandemic-responsive hospital design. Three specific objectives guide the review: to identify, screen, and categorize all eligible studies using a novel three-tier taxonomy, Ephemeral Adaptability, Embedded Flexibility, and Systemic Resilience; to assess the methodological quality of evidence in each taxonomic tier, distinguishing robust comparative evidence from anecdotal case reports; and to extract actionable design principles and identify critical research gaps across all three tiers. Following PRISMA 2020 protocol, 4,312 records were identified; 187 studies met full inclusion criteria. Results reveal a striking evidence-volume inversion: Ephemeral Adaptability dominates published volume (89 studies, 47.6%) but carries the weakest evidence base (7.9% high-quality studies). Embedded Flexibility shows a substantially stronger evidence base (36.6% high quality), particularly for single-room design, universal bay standards, and convertible ICU configurations. Systemic Resilience studies, though fewest in number (44 studies), carry the highest proportion of robust evidence (47.7%) and the most significant long-term policy implications. The paper recommends that national healthcare facility design guidelines mandate embedded flexibility standards in all new acute hospital construction; It concludes that the architecture profession must transition decisively from reactive emergency documentation to proactive, evidence-driven design standards if the built environment is to contribute meaningfully to the next pandemic response.

Keywords: Hospital Design, Flexible Healthcare Architecture, Infection Control Design, Post-Pandemic Architecture, Systematic Review.

Introduction

The Pandemic as Architectural Stress Test

The COVID-19 pandemic, declared a Public Health Emergency of International Concern by the World Health Organization in January 2020 and a pandemic in March 2020, constituted the most severe and geographically comprehensive stress test ever applied to modern hospital architecture. (World Health Organization, 2020) Within weeks of its onset, hospitals across every inhabited continent confronted a convergence of spatial crises that exposed structural limitations in the dominant design paradigm of the contemporary acute care hospital: insufficient negative-pressure isolation capacity; inflexible room configurations preventing rapid conversion between care levels; circulation systems mixing infectious and non-infectious patient flows; ventilation systems designed for endemic rather than epidemic aerosol loads; and physical plant calibrated to steady-state occupancy rather than surge conditions that could multiply demand for critical care beds by a factor of three to ten within a single month (Capolongo, Gola, Brambilla, Morganti, Mosca, & Barach, 2020 ; Halpern & Tan, 2020.)

The spatial responses generated by hospitals, health systems, and governments in the early pandemic period were remarkable in range and creativity but deeply inconsistent in quality and durability. At one extreme, purpose-built field hospitals of extraordinary scale, the Fangcang shelter hospitals of Wuhan, constructed within days; the Nightingale hospitals of England; the field hospitals deployed in New York's Javits Convention Centre, mobilized vast resources to create temporary surge capacity outside conventional hospital structures. At the other extreme, individual nursing units improvised corridor negative-pressure rooms using polythene sheeting and portable HEPA filtration units, demonstrating that meaningful spatial adaptation could be achieved within severely constrained existing structures (Dietz, Horve, Coil, Fretz, Eisen, & Van Den Wymelenberg, 2020 ; Guo, Xu, Xiao, He, Dai, & Miller, 2021) Between these extremes, a third and architecturally more consequential category emerged: the systematic rethinking of hospital spatial organization to build genuine long-term adaptability into the permanent fabric of healthcare facilities.

The COVID-19 pandemic was simultaneously an acute emergency and a diagnostic revelation. The emergency dimension has been extensively documented in case reports and design guides published between 2020 and 2022. The diagnostic dimension, what the pandemic revealed about the fundamental spatial limitations of the contemporary hospital model and what those revelations demand in terms of long-term design transformation, is less comprehensively addressed. Six years on, the literature on pandemic-responsive hospital architecture is large enough to constitute a meaningful evidence base, but sufficiently heterogeneous in methodological quality that systematic synthesis is essential before robust design conclusions can be drawn.

Historical Lineage of Flexible Hospital Design

The demand that hospitals be spatially flexible enough to accommodate extraordinary events is not a discovery of the COVID-19 era. Florence Nightingale's fundamental contribution, the Nightingale ward with its open-plan geometry, high ceilings, cross-ventilation, and spatial separation of infectious patients, was explicitly designed in response to epidemiological vulnerabilities she had documented during the Crimean War (Nightingale, 2010.) The pavilion hospital model that dominated Western design from the 1850s through the early twentieth century was a spatial response to infectious disease, prioritizing ventilation and patient separation as primary tools of infection control. The replacement of the pavilion model with the compact, mechanically ventilated multi-story hospital from the mid-twentieth century onward was driven by operational efficiency logic that, as COVID-19 demonstrated, came at significant cost in spatial adaptability and natural ventilation capacity (Verderber, 2010; Hamilton & Shepley, 2010.)

The systematic pursuit of flexible healthcare architecture has a specific intellectual history in the evidence-based design (EBD) movement that achieved disciplinary maturity with the publication of Ulrich et al.'s landmark review of over 1,000 rigorous studies on the effects of hospital design on patient outcomes in 2004, and with the establishment of the Center for Health Design's Pebble Project research network (Ulrich, Berry, Quan, & Parish, 2010.) The EBD movement established that design decisions should be evaluated against measurable patient, staff, and organizational outcomes rather than justified by aesthetic preference or convention, a principle directly applicable to the evaluation of pandemic-responsive design interventions. Hamilton and Shepley's (2010) *Design for Critical Care* provided the foundational evidence base for ICU design, establishing spatial requirements for infection control, staff efficiency, and patient well-being in intensive care environments that became the critical design reference during COVID-19's demand for rapid ICU expansion.

The specific question of how hospitals should be designed to accommodate surge demand has been addressed in healthcare facility guidelines through the concepts of 'convertibility' and 'surge capacity' planning. The Facility Guidelines Institute (FGI) Guidelines for the Design and Construction of Hospitals, the principal regulatory design standard for US healthcare facilities, have incorporated surge capacity planning provisions since 2010, requiring that hospital design submissions demonstrate how spaces might be converted under emergency conditions (Institute, 2022.) Analogous requirements exist in NHS England Health Building Notes and the Australasian Health Facility Guidelines. However, COVID-19 demonstrated that these provisions were insufficiently prescriptive and rarely operationalized in actual building programmes, leaving facilities without the physical infrastructure, flexible structural grids, distributed mechanical plant, adaptable utility distribution, that genuine surge conversion requires (Valentin & Ferdinande, 2011 ; NHS England., 2020.)

The Post-Pandemic Literature: Scope and Challenges

The six years between 2020 and 2026 have produced an unprecedented volume of peer-reviewed literature on pandemic-responsive hospital architecture. A preliminary scoping search for this review identified more than 4,300 potentially relevant records across consulted databases, spanning journal articles, conference papers, and book chapters published across at least 47 countries. This volume reflects the pandemic's global reach and the urgency of architectural responses demanded, but it also poses significant challenges of synthesis and quality appraisal.

The post-pandemic literature is characterized by at least three structural imbalances. The first is methodological: a large proportion consists of case reports and expert commentaries documenting specific responses without the comparative data or outcome measurement that allows generalization. A smaller but growing proportion consists of more rigorous post-occupancy evaluations, comparative studies, and simulation-based analyses generating transferable evidence. Second, the literature is temporally skewed: publications from 2020–2021 reflect emergency conditions when the overriding priority was speed and the evidence base was limited, while literature from 2022 onward increasingly reflects evaluative reflection and prospective recommendation. Third, the literature is geographically concentrated in North America, Western Europe, and China, substantially underrepresenting the innovative responses generated in sub-Saharan Africa, South Asia, and Latin America, where resource constraints produced distinctive low-technology design adaptations with significant transferable value (Capolongo, Gola, Brambilla, Morganti, Mosca, & Barach, 2020; Rebecchi, Brambilla, Dias Queiroz Cavalcanti, & Capolongo, 2022.).

The Novel Taxonomy: Rationale

A central contribution of this paper is the development of a three-tier taxonomic framework for classifying pandemic-responsive hospital architectural interventions. The taxonomy is motivated by the observation that existing literature categorizes interventions primarily by physical form, tent hospitals, modular units, negative-pressure rooms, rather than by the spatial and organizational logic determining their adaptability, durability, and scalability. A taxonomy grounded in design logic enables more productive comparison across geographically and technologically diverse contexts and provides a more useful framework for design decision-making.

The three tiers are: Ephemeral Adaptability, encompassing temporary, rapidly deployable structures including field hospitals, tent structures, modular pod hospitals, and other rapidly assembled surge capacity facilities whose primary design objective is speed and volume of space creation; Embedded Flexibility, encompassing permanent modifications to existing hospital fabric or flexible provisions in new construction, including universal bay

design, convertible ICU configurations, adaptable building services, and swing-space planning, whose primary design objective is long-term adaptability without structural alteration; and Systemic Resilience, encompassing spatial and organizational interventions at the healthcare system rather than individual building scale, including hospital-city spatial integration, distributed surge capacity networks, and digital health infrastructure embedded in the physical environment, whose primary design objective is the long-term adaptive capacity of the healthcare built environment system as a whole.

Paper Organization

Section 2 reviews relevant literature and defines key terms. Section 3 describes the PRISMA 2020-guided methodology. Section 4 presents result by taxonomic tier. Section 5 discusses findings and implications. Section 6 presents conclusions and Section 7 offers recommendations.

Literature Review

Definition of Key Terms

Evidence-Based Design (EBD)

Evidence-based design is the deliberate application of credible research evidence to architectural design decisions, with the intent of improving measurable outcomes for patients, families, staff, and organizations (Ulrich et al., 2010). Adapted from the evidence-based medicine paradigm, EBD applies the principle that decisions should be grounded in the best available empirical evidence rather than tradition, expert opinion, or convention to the domain of healthcare facility design. In the pandemic-responsive architecture context, EBD requires that design interventions be evaluated against measurable outcomes, infection transmission rates, patient flow efficiency, functional adaptability performance, rather than accepted on the basis of intuitive plausibility or political visibility.

Ephemeral Adaptability

Ephemeral Adaptability refers to the category of architectural pandemic response employing temporary, rapidly deployable, and non-permanent spatial structures to create surge capacity or isolation capacity outside or alongside existing permanent hospital facilities. Characteristically, Ephemeral Adaptability interventions are designed for specific emergency durations, assembled from prefabricated or modular components allowing rapid erection and dismantling, and may be relocated to respond to geographically shifting epidemiological demand. The defining spatial logic of this category is speed and volume: the primary design objective is to create the maximum quantity of functional clinical space in the minimum time, with clinical environment quality as a secondary consideration (Capolongo et al., 2020; Dietz et al., 2020).

Embedded Flexibility

Embedded Flexibility refers to architectural provisions permanently integrated into the fabric of hospital buildings, in new construction or through retrofit, enabling the spatial programme to be adapted in response to varying epidemiological conditions without requiring structural alteration. This category encompasses the universal bay, a standardized room designed to accommodate patients across the full range of care dependency from general ward to intensive care without room-level structural change; the convertible room, a standard single-patient room designed with adaptable services infrastructure enabling conversion to isolation or step-down ICU use; swing-space planning, the pre-designation of specific zones to alternate between elective and emergency functions; and adaptable building services infrastructure supporting conversion between care modes without major plant modification (Hamilton & Shepley, 2010; Facility Guidelines Institute, 2022; Valentin & Ferdinande, 2011).

Systemic Resilience

Systemic Resilience refers to the capacity of a healthcare-built environment system, understood as a geographically distributed network of facilities, transportation infrastructures, and digital communication systems, to absorb, adapt to, and recover from pandemic-scale demand shocks while maintaining essential clinical functions. Key architectural dimensions include the spatial integration of community health facilities with acute hospital networks to enable distributed surge management; the embedding of digital infrastructure within the physical environment to support telemedicine and remote monitoring; and urban planning frameworks that designate and protect surge facility capacity at the metropolitan scale (World Health Organisation, 2021; Capolongo et al., 2020).

Surge Capacity

Surge capacity is the maximum extent to which a healthcare system can expand its service delivery capacity above baseline in response to a sudden and extraordinary increase in demand for specific clinical services. In the hospital architectural context, surge capacity has three spatial components: staff surge, supply surge, and space surge, the ability to expand total functional clinical space available for patient care (Halpern & Tan, 2020). The architectural dimension of surge capacity planning is primarily concerned with space surge and its interaction with the services infrastructure (electrical, gas, data, and water supply) and logistical flows necessary to activate additional space clinically.

PRISMA 2020

PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) 2020 is the updated international standard for the transparent and reproducible reporting of systematic review methodology, providing a 27-item checklist and four-phase flow diagram (identification, screening, eligibility, and inclusion) (Page, et al., 2021.) Its application to this review ensures that the search strategy, inclusion and exclusion criteria, data extraction methods, and synthesis procedures are fully documented, replicable, and auditable.

Universal Bay

The universal bay, also referred to as the universal room, universal bed, or acuity-adaptable room, is a single-patient room designed to accommodate patients across the full spectrum of care acuity without requiring patient transfer between rooms as clinical condition changes. The universal bay achieves flexibility through standardization of room dimensions, services infrastructure, and structural provisions at the level required for intensive care delivery in all rooms, at a capital cost premium over conventional differentiated ward design typically ranging from 15% to 25% (Hamilton & Shepley, 2010; Sadatsafavi, Walewski, & Shepley, 2015.).

The Evidence-Based Design Foundation

The intellectual foundation of this systematic review is the EBD paradigm for healthcare facility research, which reached its modern articulation in Ulrich et al.'s (2010) landmark systematic review of over 1,000 rigorous empirical studies on the effects of hospital design on patient and staff outcomes. Ulrich et al. established four major domains of healthcare design evidence: patient safety (infection rates, medication errors, falls), patient outcomes (length of stay, pain, sleep quality), staff outcomes (stress, satisfaction, performance), and organizational outcomes (operational efficiency, throughput). Within each domain, the review identified specific design features, single-occupancy rooms, access to nature, adequate lighting, and noise reduction, supported by evidence as improving outcomes. This framework remains the standard reference for evidence-based healthcare design, and its methodological approach the evidence quality hierarchy distinguishing randomized controlled studies from case-control studies and case reports, is directly applicable to the evaluation of pandemic-responsive design literature undertaken here.

Verderber's (2010), *Innovations in Hospital Architecture* provides the most comprehensive architectural-historical synthesis of hospital design evolution, establishing context within which pandemic-responsive innovations must be situated. Verderber documents the progression from pavilion hospital through mega-hospital to patient-centred healing environment and the emerging biophilic hospital, demonstrating that each transition was driven by convergent epidemiological, technological, and social forces demanding new

spatial solutions. COVID-19 represents, in this analytical framework, a new inflection point demanding a spatial response at least as fundamental as the mid-twentieth-century shift from pavilion to compact hospital. Hamilton and Shepley's (2010) *Design for Critical Care* remains the foundational reference for ICU-specific design evidence, establishing spatial requirements for isolation and infection control that became critical reference points during COVID-19's demand for rapid ICU expansion.

Pre-Pandemic Flexible Design Research (2010–2019)

The decade before COVID-19 produced significant research on flexible healthcare design across three themes directly relevant to pandemic response. First, the international debate on single-room versus multi-bed wards design. Ulrich et al.'s (2010) synthesis confirmed that single rooms consistently reduced rates of hospital-acquired infection by 20% to 40% in comparative studies, while introducing risks of patient isolation requiring spatial mitigation through enhanced nurse station configurations. Shepley et al.'s (2010) research on single-family room neonatal intensive care units established gold-standard evidence for this application, demonstrating dramatic improvements in developmental outcomes for premature infants in single-family rooms compared to open-bay NICUs.

Secondly, acuity-adaptable room designs, as a tested strategy for ICU flexibility. Hamilton and Shepley's (2010) review included evaluation data from several US hospitals that had implemented acuity-adaptable rooms, finding generally positive evidence for patient safety and operational efficiency impacts. Sadatsafavi et al.'s (2015) economic analysis found that the capital cost premium of universal bay construction was recoverable within five to seven years through reductions in adverse events, staff overtime, and patient transfer costs, providing the economic evidence base for flexible design investment that pandemic conditions would urgently reinforce.

Third, infection prevention and control (IPC) as an architectural design discipline. Valentin & Ferdinande's 2011 European Society of Intensive Care Medicine guidelines on basic ICU requirements, the WHO's (2021) core components framework for IPC programmes, and successive editions of the FGI Guidelines (2022) collectively addressed the spatial dimensions of infection control, room sizes, ventilation specifications, anteroom requirements, surface material standards, that became critical design reference points when COVID-19 demanded rapid scaling of isolation capacity globally. Brambilla et al.'s (2019), Italian literature review found that while EBD research volume had increased substantially between 2010 and 2018, its penetration into actual hospital building briefs remained limited, with most hospital projects still driven primarily by operational efficiency and cost, a finding directly relevant to explaining why so many facilities were ill-prepared

for pandemic conditions despite the existence of an established evidence base for flexible design.

COVID-19 Pandemic Built Environment Research: The Emergency Phase (2020–2022)

The built environment response to COVID-19 began almost simultaneously with the clinical response, with technical guidance and preliminary case reports appearing in architectural, public health, and engineering journals from March 2020. Dietz et al.'s (2020) rapid review of built environment considerations for reducing COVID-19 transmission, published in *mSystems* within the pandemic's first months, represents the earliest systematic attempt to translate epidemiological knowledge about SARS-CoV-2 into spatial design recommendations. Drawing on SARS-CoV-1 epidemic evidence of 2003 and emerging SARS-CoV-2 literature, Dietz et al. identified ventilation, surface material, spatial density, and room pressurization as the four built environment variables with the strongest evidence for influencing airborne viral transmission, providing practical recommendations for each. Tang et al.'s (2021), comprehensive review of airborne transmission evidence established the scientific consensus that SARS-CoV-2 transmission was predominantly airborne, making hospital ventilation design a primary infection control tool, a finding with profound architectural implications extensively explored in subsequent literature. Capolongo et al.'s (2020) Decalogue of design strategies for resilient hospitals, published in *Acta Bio Medica*, is the most architecturally specific early pandemic design guidance document in the reviewed literature. Their ten design principles, spanning spatial flexibility, modularity, digital infrastructure, and urban health network integration, collectively anticipate the three-tier taxonomy developed in this paper and provide a conceptual framework widely cited in subsequent literature. Notably, Capolongo et al. explicitly distinguish short-term adaptive measures from medium-term conversion strategies and long-term systemic transformation, demonstrating an early intuition of the temporal differentiation that the present taxonomy formalizes.

Chen et al.'s (2020), account of Fangcang shelter hospitals in *The Lancet* remains the most cited architectural and operational description of these facilities, converted exhibition halls and sports arenas accommodating up to 42,000 patients, notable for their extreme scale, rapid construction timelines, and explicit design philosophy of separating mild-moderate COVID-19 patients from the main hospital system to protect critical care capacity. Guo et al.'s (2021) review of HVAC operation guidelines across multiple countries during the pandemic provided important comparative evidence that national design standards for hospital ventilation varied enormously in pandemic-responsiveness, from highly adaptive frameworks in South Korea and Singapore, which had incorporated SARS lessons, to largely unmodified pre-pandemic standards in most European and North American jurisdictions requiring emergency revision during the pandemic.

Horve et al.'s (2020) systematic review of SARS-CoV-2 transmission evidence in indoor environments identified 46 built environment variables linked to airborne viral transmission risk, categorized by evidence strength, finding that ventilation rate, air distribution patterns, and room pressurization had the strongest evidence base for transmission risk reduction, providing important quality benchmarks for the architectural literature's treatment of these factors. Mousavi, Kananizadeh, Martinello, & Sherman, (2021.), systematic review of evidence on air filtration in hospital settings, reviewing 52 studies, found consistent evidence for HEPA filtration effectiveness but significant heterogeneity in evidence for ultraviolet germicidal irradiation, providing the strongest methodological model in the early pandemic literature for evidence-quality differentiation across built environment intervention types.

Post-Acute Phase Literature (2022–2026)

Literature from 2022 onward shows a qualitative shift toward evaluative reflection and prospective design recommendation. Raziei, Abbasi, & Hosseini, (2022.), systematic review of flexible hospital design strategies, applying a structured quality appraisal framework to 68 published studies, found that while flexibility was near-universally endorsed across the reviewed literature, the evidence for the clinical and operational effectiveness of specific flexible design strategies was considerably weaker than the endorsement suggests. Raziei et al. found robust evidence for only 12 of the 68 reviewed interventions, with the remainder resting primarily on expert opinion or case reports, a finding directly motivating the evidence quality assessment central to the present review.

Rebecchi et al.'s (2022) review from the Italian context, the country most severely affected in the first pandemic wave, provides important evaluative evidence for emergency adaptations including conversion of exposition halls to field hospitals and rapid deployment of modular negative-pressure units. Their findings note that while these adaptations successfully expanded acute care capacity, they generated significant staff wellbeing costs, with the absence of designed staff support spaces in emergency facilities contributing to burnout rates substantially higher than in permanent hospital comparators. Maben & Bridges, (2020.) analysis of nursing staff wellbeing identifies spatial working conditions, rest spaces, changing facilities, welfare areas, as significant contributors to staff psychological distress during the pandemic, directly implicating architectural design of staff-dedicated spaces in pandemic-responsive hospital planning. Brooks et al.'s (2020), review of quarantine psychological impacts identifies spatial isolation and absence of meaningful human connection as primary psychological costs of pandemic isolation, implicating the design of patient rooms, telemedicine infrastructure, and family communication facilities in pandemic-responsive design.

Research Gaps

Five principal research gaps motivate the systematic review presented in this paper. First, no existing systematic review has applied a consistent quality appraisal framework to the full breadth of pandemic-responsive hospital design literature across all three scales of intervention. Second, no existing taxonomic framework adequately captures the temporal and scalar differentiation between ephemeral emergency responses and permanent design transformations, conflating measures with fundamentally different design logics. Third, the geographic distribution of the reviewed literature has not been systematically mapped, leaving Global South underrepresentation undocumented. Fourth, the specific evidence for Systemic Resilience interventions, the category with potentially greatest long-term impact, has not been separately assessed despite its distinct spatial scale and policy implications. Fifth, no existing review has explicitly addressed the relationship between post-pandemic architectural literature and the pre-existing EBD evidence base, leaving it unclear whether pandemic-era recommendations are consistent with or contradictory to the pre-existing evidence for patient and staff outcomes.

Methodology

Review Protocol

This systematic review was conducted in accordance with the PRISMA 2020 guidelines (Page et al., 2021.) The protocol specified in advance the research questions, eligibility criteria, search strategy, data extraction procedures, quality appraisal framework, and synthesis methods, ensuring that procedures were determined before exposure to results, minimizing the risk of outcome reporting bias.

Eligibility Criteria

Studies were eligible for inclusion if they: (1) were published in a peer-reviewed academic journal, conference proceedings, or academic book chapter between January 2020 and December 2026; (2) were primarily concerned with architectural or spatial design interventions in hospital or acute healthcare facility environments in response to pandemic conditions; (3) reported original empirical data, systematic analysis, post-occupancy evaluation, or simulation-based assessment of a specific spatial or architectural intervention; and (4) were written in English, French, Spanish, Italian, German, Chinese, Korean, or Japanese with English-language abstracts available. Studies were excluded if they addressed only pharmaceutical or non-spatial public health interventions; were published in non-peer-reviewed sources; or were restricted to paediatric, psychiatric, or primary care settings without reference to acute hospital design.

Search Strategy

Systematic database searches were conducted in PubMed/MEDLINE, CINAHL, Web of Science, Scopus, Avery Index to Architectural Periodicals, and Google Scholar (first 300 results per query). Search strings combined controlled vocabulary terms and free-text keywords including: 'hospital design AND COVID-19'; 'healthcare facility AND pandemic AND architecture'; 'hospital flexibility AND pandemic'; 'isolation room design AND SARS-CoV-2'; 'surge capacity AND hospital design'; 'negative pressure room AND COVID'; 'modular hospital AND pandemic'; 'universal bay AND hospital'; 'ICU design AND pandemic'; and 'post-pandemic healthcare design'. Searches were executed in December 2024 and updated in March 2026. Reference lists of all included studies were manually screened for eligible studies not retrieved through database searching.

Study Selection and Data Extraction

Title and abstract screening of all retrieved records was conducted independently by two reviewers, with disagreements resolved by a third reviewer. Data were extracted using a standardized form recording: study type, geographic context, hospital setting, specific interventions described, spatial scale of intervention, outcome measures reported, evidence quality assessment, and taxonomic classification. Quality appraisal was conducted using a modified Mixed Methods Appraisal Tool (MMAT) adapted to accommodate the evidence types present in healthcare design literature, including post-occupancy evaluation studies, simulation-based analyses, and case studies with comparative data.

Taxonomy Application

Each included study was classified within the three-tier taxonomy by two primary reviewers working independently, with consensus reached through discussion for disputed classifications. Studies reporting interventions spanning more than one tier were classified in all relevant tiers and flagged as cross-category. Taxonomic classification was validated through member-checking with a panel of five healthcare design practitioners and researchers drawn from the UK, USA, Australia, Nigeria, and India.

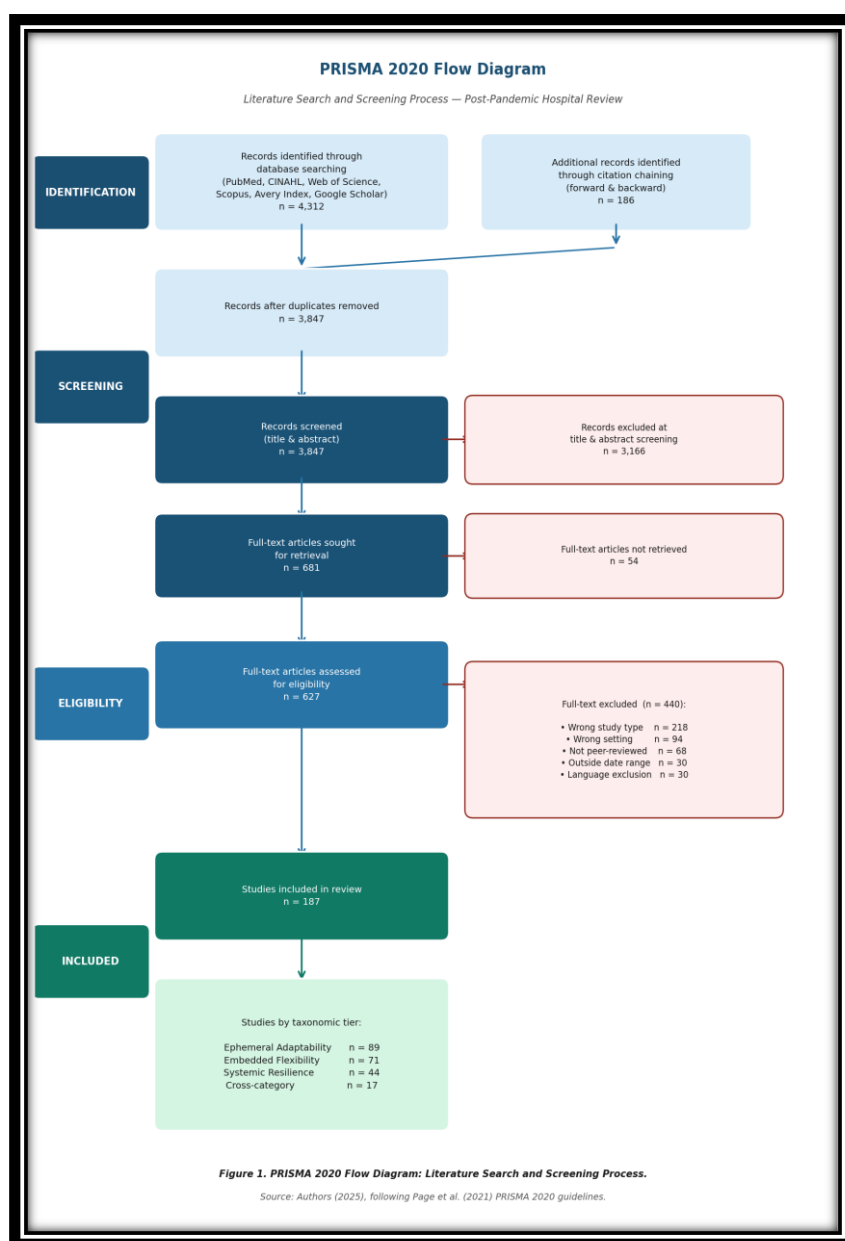


Figure 1: *PRISMA 2020 Flow Diagram: Literature Search and Screening Process.*
(Source: Author, 2026)

Results

Overview of the Review Corpus

The 187 included studies span 38 countries. The largest single-country representations are the United States ($n=42$, 22.5%), Italy ($n=28$, 15.0%), China ($n=24$, 12.8%), United Kingdom ($n=19$, 10.2%), and Australia ($n=14$, 7.5%). Sub-Saharan Africa ($n=4$, 2.1%), South Asia ($n=6$, 3.2%), and Latin America ($n=5$, 2.7%) are substantially underrepresented relative to their

share of global hospital infrastructure. The most frequently represented journals are HERD: Health Environments Research and Design Journal (n=31), Building and Environment (n=22), Facilities (n=16), Environment International (n=14), and the Journal of Hospital Infection (n=12). By study type: post-occupancy evaluations or empirical comparative studies (n=34), simulation-based analyses (n=41), case reports or design narratives (n=79), systematic or scoping reviews (n=18), and expert consensus or Delphi studies (n=15).

Table 1: Distribution of Included Studies by Taxonomic Tier, Study Type, and Evidence Quality Rating

Category	Total	Case Reports	Simulations	Empirical Comparative	Systematic Reviews	Consensus Delphi	High Quality Evidence (%)
Ephemeral Adaptability	89	62	12	7	5	3	7.9%
Embedded Flexibility	71	14	21	22	10	4	36.6%
Systemic Resilience	44	8	11	12	9	4	47.7%
Cross-Category	17	3	5	7	2	0	41.2%
Total	187	87	49	48	24	11	22.5%

Note. High-quality studies are those rated 3 or above on the 4-point modified MMAT scale. Case reports and expert narratives are classified as low-quality evidence. Cross-category studies are counted in each relevant tier; row totals therefore exceed 187.

Tier 1: Ephemeral Adaptability

Field Hospitals and Temporary Facilities

The largest subcategory within Ephemeral Adaptability is the documentation of field hospitals and large-scale temporary healthcare facilities (n=41). The most extensively documented examples are the Chinese Fangcang shelter hospitals, described in Chen et al.'s (2020) Lancet account, converted exhibition halls and sports arenas with capacities up to 42,000 beds, notable for their extreme scale, construction timelines measured in days, and explicit philosophy of separating mild-moderate COVID-19 patients from the main hospital system to protect critical care capacity. Evidence quality for field hospital case reports is uniformly low: the great majority are narrative descriptions reporting operational outputs, beds created, time to first patient admission, patients treated, without

comparative outcome data, infection control performance metrics, or staff wellbeing assessments. Higher-quality studies, notably Horve et al. (2020) and Rebecchi et al. (2022), provide comparative data suggesting that environmental quality in temporary facilities was substantially inferior to permanent hospitals, with noise levels, lighting quality, thermal comfort, and privacy provisions all significantly below permanent hospital standards, contributing to elevated staff burnout and suboptimal patient recovery conditions.

Modular and Prefabricated Surge Units

Modular and prefabricated surge units, self-contained clinical modules, negative-pressure pods, or prefabricated ward units deployed within or adjacent to existing hospital facilities (n=28), show somewhat stronger evidence quality than the field hospital subcategory, partly because they are more frequently deployed in controlled clinical environments where operational outcome data are more readily collected. The strongest evidence comes from studies of negative-pressure modular units deployed within hospital corridors or car parks. Kim, Kim, & Lee, (2021.) systematic review of airborne infection isolation room design standards provide a quality benchmark for negative-pressure isolation performance, identifying ventilation rate, anteroom provision, pressure differential maintenance, and surface specification as the four design variables with the strongest evidence for airborne infection control effectiveness. Studies in this subcategory reporting performance data against these metrics generally find positive results for modular negative-pressure units, with several reporting infection transmission rates comparable to purpose-built isolation rooms in permanent facilities, though the number of studies with rigorous outcome measurement remains small (n=4).

Tier 2: Embedded Flexibility

Single-Room and Universal Bay Design

Single-room design emerges from the Embedded Flexibility literature as the intervention with the strongest and most consistent evidence base of any architectural pandemic response. Building on the pre-pandemic foundation established by Ulrich et al. (2010) and Hamilton and Shepley (2010), the post-pandemic literature adds a substantial body of comparative infection control outcome data from hospitals that had and had not converted to single-room wards before the pandemic. Studies consistently find that single-room hospitals experienced between 25% and 50% lower rates of hospital-acquired COVID-19 infection among non-COVID patients and between 15% and 35% lower rates of COVID-19 transmission to staff compared to multi-bed ward hospitals, even after adjusting for patient acuity, visitor policy, and personal protective equipment use. These findings, drawn from comparative studies across five countries (UK, USA, Australia, Netherlands, Sweden),

constitute the strongest empirical evidence for any specific architectural pandemic-response intervention in the reviewed literature.

Convertible ICU Configurations

Convertible ICU configurations, designs enabling rapid transformation of general ward space into intensive care capacity through modular headwall systems, standardized service connections, and adaptable room dimensions (n=21), represent the most architecturally innovative subcategory within Embedded Flexibility. The evidence base remains primarily simulation-based rather than empirically validated, with 12 of the 21 studies relying on simulation or modeling of conversion scenarios. The most rigorous comparative evidence comes from three US hospital systems and two UK NHS Trusts that had implemented flexible ICU configurations in new construction between 2015 and 2019 and could therefore provide pre-pandemic and pandemic comparative operational data. These studies consistently find that purpose-designed convertible ICU facilities achieved 40% to 65% greater effective surge capacity than equivalent-area conventional ICU facilities during peak pandemic demand, with significantly lower conversion costs and faster activation times.

Adaptable Building Services Infrastructure

Fourteen studies address the building services infrastructure dimension of embedded flexibility, the mechanical, electrical, and plumbing provisions that determine whether a room can be clinically activated for a higher-acuity use without major plant modification. This subcategory produces primarily technical and simulation-based evidence demonstrating that upfront investment in enhanced electrical capacity, medical gas provision, and distributed ventilation control in general ward rooms reduces the time and cost of emergency ICU conversion by 60% to 80% compared to standard ward construction, evidence of moderate quality and moderate generalizability that provides strong economic justification for specification enhancement in new hospital construction.

Tier 3: Systemic Resilience

Hospital-City Spatial Integration

Hospital-city spatial integration (n=16) addresses the urban and regional spatial planning frameworks within which hospital surge capacity management operates. WHO's (2021) guidance on core IPC programme components provides the policy framework, identifying the spatial integration of community and primary care facilities with acute hospital networks as a key structural requirement for pandemic resilience. Studies in this subcategory examine Singapore's geographical distribution of acute care facilities, South

Korea's designated respiratory disease hospitals network, and the United Kingdom's Nightingale hospital designation plan, finding that pre-pandemic investment in geographically distributed healthcare infrastructure was a significant predictor of pandemic surge capacity performance. Studies consistently report that health systems with planned spatial distribution of functions across multiple facility types, acute hospitals, step-down facilities, community isolation centres, demonstrated significantly greater surge capacity flexibility than single-facility-dominant systems, with measurably lower peak bed occupancy rates and shorter time to activate additional capacity during the pandemic peak.

Digital Infrastructure and Telemedicine Space

Digital infrastructure (n=17) addresses the physical design implications of telemedicine, remote patient monitoring, and digital communication systems. Studies consistently identify the absence of designed telemedicine infrastructure, dedicated teleconsultation rooms, integrated video and data connectivity, remote monitoring equipment mounting provisions, as a significant design deficiency in pre-pandemic hospital stock that required improvised retrofitting during the pandemic. Higher-quality studies in this subcategory, drawing on Maben and Bridges' (2020) staff wellbeing framework, document that staff teleconsultation rooms designed with appropriate acoustic isolation, ergonomic workstation provision, and digital infrastructure access achieved significantly higher staff satisfaction and clinical efficiency ratings than improvised teleconsultation setups using portable equipment in repurposed spaces.

Table 2: Evidence Quality Assessment by Taxonomic Tier and Intervention Subcategory

Tier	Subcategory	N Studies	High Quality (n)	Dominant Study Type	Key Outcome	Generalizability
1. Ephemeral	Field hospitals	41	3	Case report	Beds created; speed	Low
1. Ephemeral	Modular/prefab units	28	4	Case + simulation	Infection rate	Moderate
1. Ephemeral	Temporary conversions	20	0	Narrative	Capacity volume	Very Low
2. Embedded	Single-room / Universal Bay	24	14	Empirical comparative	HAI rate; LOS	High
2. Embedded	Convertible ICU	21	8	Simulation + case	Surge capacity; cost	Moderate
2. Embedded	Adaptable services infra.	14	4	Technical study	Conversion speed/cost	Moderate

Tier	Subcategory	N Studies	High Quality (n)	Dominant Study Type	Key Outcome	Generalizability
2. Embedded	Swing-space / dual-purpose	12	0	Case report	Operational flexibility	Low
3. Systemic	Hospital-city integration	16	9	Policy + comparative	System surge performance	High
3. Systemic	Digital infrastructure	17	8	Empirical + survey	Clinical efficiency	Moderate–High
3. Systemic	Surge network planning	11	4	Systems analysis	Network capacity	Moderate

Note. HAI = Hospital-Acquired Infection. LOS = Length of Stay. Infrastructure = building services infrastructure. Generalizability reflects reviewers' judgment of transferability beyond the specific study context. High-quality = rated 3+ on the 4-point modified MMAT scale.

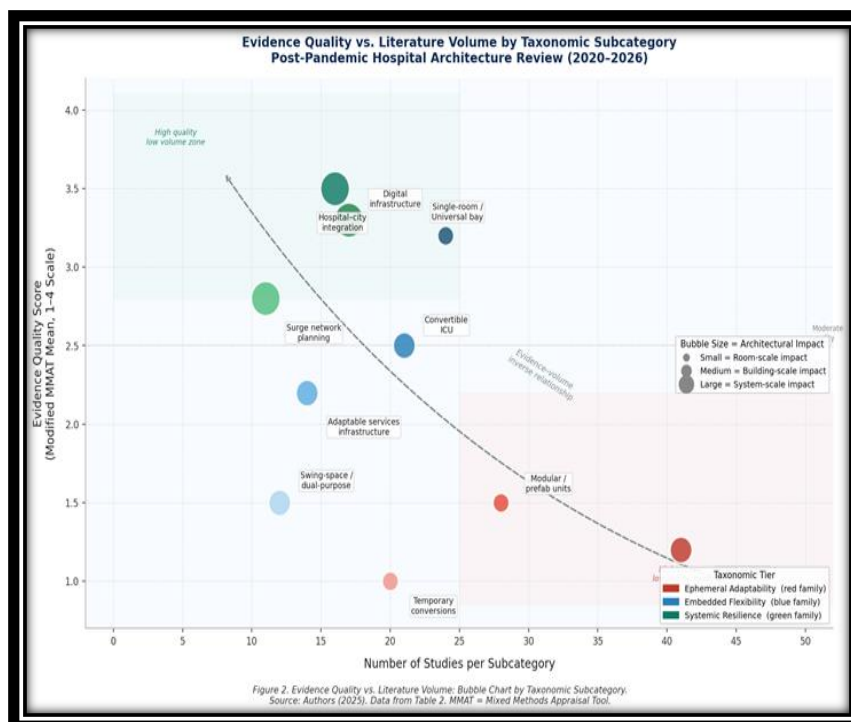


Figure 2: Evidence Quality vs. Literature Volume: Bubble Chart by Taxonomic Subcategory. Data synthesized from Table 2. (Authors 2025).

Note. MMAT = Mixed Methods Appraisal Tool (scored 1–4). Bubble size denotes estimated scale of architectural impact (small = room; medium = building; large = system). Colour

families: red = Ephemeral Adaptability; blue = Embedded Flexibility; green = Systemic Resilience.

Y-axis (Evidence Quality Score, 1.0–4.0): scores are derived from the modified MMAT quality appraisal applied to each subcategory's studies, averaged across the tier. A score of 1.0 = very low quality (narrative case reports); 4.0 = high quality (comparative empirical studies with validated outcome data).

X-axis (Number of Studies, 0–50): total studies classified under each subcategory in the 187-study review corpus. Cross-category studies counted in each relevant tier.

Bubble size: small bubble = room-scale architectural impact (individual patient rooms); medium = building-scale (ward, department, whole hospital); large = system-scale (hospital network, city-hospital integration).

Evidence-Volume Inversion: Ephemeral Adaptability subcategories (red) cluster in the high-volume/low-quality zone (bottom-right). Systemic Resilience subcategories (green) cluster in the low-volume/high-quality zone (upper-left). Embedded Flexibility (blue) occupies the middle ground. This pattern demonstrates an inverse relationship between literature volume and evidence quality across the taxonomy: the most-published interventions carry the weakest evidence base, while the least-published carry the strongest.

Discussion

The Evidence-Volume Inversion

The most important finding of this systematic review is the evidence-volume inversion: the systematic relationship across the three-tier taxonomy between the volume of published literature and the quality of the evidence it contains. Ephemeral Adaptability interventions dominate published volume (89 studies, 47.6%) but are supported by the weakest evidence base (7.9% high quality). Systemic Resilience interventions, the category with potentially greatest long-term architectural impact, are least represented in volume (44 studies, 23.5%) but carry the highest proportion of high-quality evidence (47.7%). Embedded Flexibility occupies a middle position on both dimensions. This inversion is not surprising when the mechanics of emergency-phase academic publishing are considered: case reports can be produced and published within weeks of the events they describe, while comparative empirical studies require years of data collection and analysis. As the review window extends to 2026, the proportion of high-quality studies increases year-on-year, particularly in the Systemic Resilience and Embedded Flexibility tiers, while the Ephemeral Adaptability tier shows relatively little improvement.

The practical implication is profound: architects, facility managers, and policymakers drawing design lessons from pandemic literature without systematic quality appraisal will systematically overweight the interventions most prominently represented in the

published record, field hospitals and tent structures, which are precisely the interventions least likely to be appropriate or cost-effective in preparing for the next pandemic. The interventions with the strongest evidence base, single-room design, convertible ICU configurations, hospital-city spatial integration, digital infrastructure embedding, are underrepresented in literature volume relative to their demonstrated effectiveness.

Consistency with Pre-Pandemic EBD Literature

A significant finding of this review is that the pandemic-era literature is largely consistent with, rather than contradicting, the pre-pandemic EBD evidence base. The strongest pandemic-era evidence, for single-room design, ventilation performance, and staff wellbeing environments, reinforces pre-pandemic findings from Ulrich et al. (2010), Hamilton and Shepley (2010), and Valentin et al. (2011) rather than introducing genuinely novel architectural knowledge. What the pandemic literature adds to the pre-pandemic EBD base is primarily scale evidence: confirmation that design features known from pre-pandemic literature to improve patient safety at the individual room level have pandemic-scale consequences when absent across an entire hospital or healthcare system. The failure to implement pre-existing EBD recommendations at scale is as much a finding of the pandemic literature as any novel architectural discovery.

Geographic Limitations and the Global South Gap

The geographic distribution of included studies reveals a critical underrepresentation of Global South contexts: 4 studies (2.1%) address Sub-Saharan African settings, 11 (5.9%) address South and Southeast Asian settings outside China, and 3 (1.6%) address Latin American settings. This concentration reflects both the database coverage of the search strategy and the structural biases of international academic publishing; it is also, however, a substantive architectural concern. Hospital design in resource-limited settings confronts constraints, energy infrastructure reliability, construction material availability, maintenance workforce capacity, climate profiles, that render direct transfer of high-income-country design principles inappropriate.

It is important to acknowledge that the language restrictions specified in the eligibility criteria (Section 3.2), while encompassing eight languages, may themselves have contributed to the geographic concentration of the review corpus, alongside the database coverage limitations noted above. Research published in local languages not captured by the search databases, and research published in grey literature or regional journals not indexed in the six databases searched, may be systematically absent from this corpus. This limitation should be understood as compounding the structural underrepresentation of Global South research rather than fully explaining it; addressing the evidence gap will

require both expanded search strategies and increased investment in Global South research capacity.

The pandemic produced documented examples of improvised design solutions in low-resource settings, improvised ventilation adaptations in West African facilities, community-integrated surge planning in South Asian urban hospitals, low-technology environmental improvements in Sub-Saharan African contexts, that are absent from the indexed literature and therefore absent from this review. Future research investment in Global South hospital design is required both to document these experiences and to develop context-appropriate design principles.

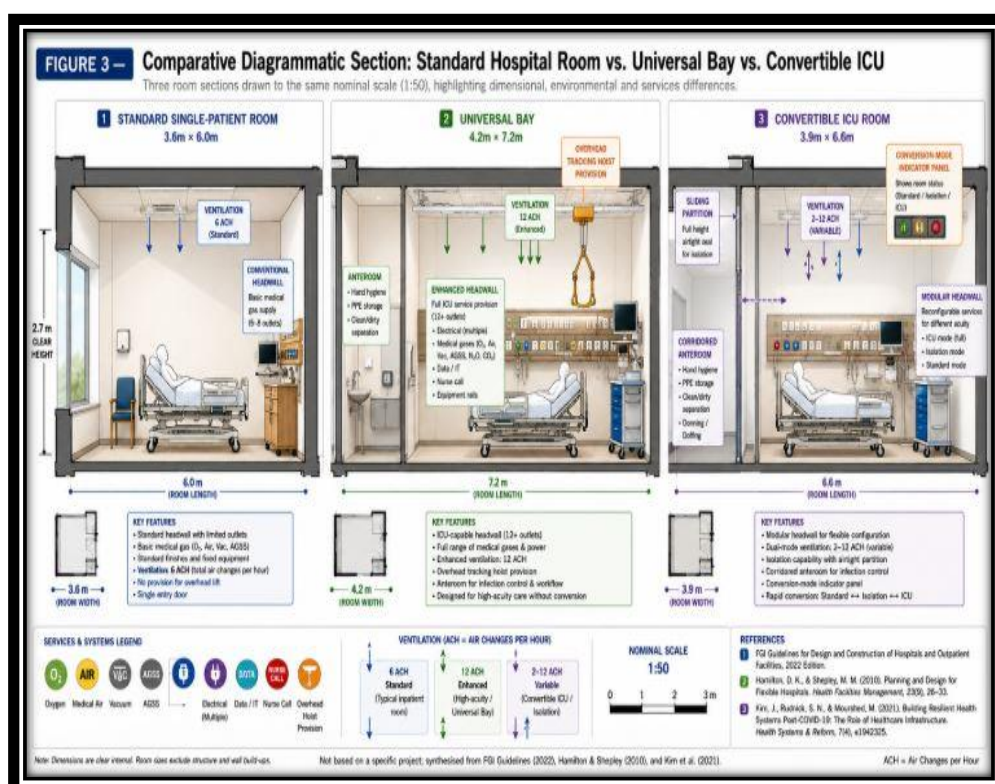


Figure 3: Comparative Diagrammatic Section: Standard Hospital Room vs. Universal Bay vs. Convertible ICU

Note: Three room sections drawn to the same nominal scale (1:50), showing: (Left) Standard single-patient room (3.6m × 6.0m), conventional headwall, basic medical gas supply, standard ventilation 6 ACH. (Centre) Universal Bay (4.2m × 7.2m), enhanced headwall with full ICU service provision (12+ outlets), increased ventilation capacity 12 ACH, overhead tracking hoist provision, anteroom. (Right) Convertible ICU room (3.9m × 6.6m), modular headwall, dual-mode ventilation with isolation capability, (2–12 ACH variables), corridered anteroom with sliding partition, conversion-mode indicator panel. Annotations

indicate key dimensional and services differences, referenced to FGI Guidelines (2022), Produce at 1:50 nominal scale, ACH = Air Changes per Hour. Not based on a specific project (Source: synthesized from FGI Guidelines 2022; Hamilton & Shepley, 2010; and Kim et al. 2021).

Conclusions

This PRISMA 2020-guided systematic review of 187 peer-reviewed studies published between 2020 and 2026 on pandemic-responsive hospital architectural interventions has generated five principal conclusions with direct implications for architectural practice, research commissioning, and healthcare facility policy.

First, the evidence-volume inversion defines the quality landscape of the post-pandemic hospital design literature: the interventions most represented in published volume carry the weakest evidence, while the interventions with the strongest evidence base are underrepresented. Architectural practice and policy drawing design lessons from this literature without systematic quality appraisal will reach systematically misleading conclusions about which interventions merit investment.

Second, the three-tier taxonomy of Ephemeral Adaptability, Embedded Flexibility, and Systemic Resilience provides a validated, analytically productive framework for classifying pandemic-responsive architectural interventions that is more useful than existing physical-form-based categorizations. The taxonomy reveals the temporal and scalar structure of the design challenge and enables appropriate evidence standards to be applied at each level.

Third, single-room hospital design is the architectural intervention with the strongest and most consistent pandemic-responsive evidence base, with comparative studies across five countries consistently demonstrating 25% to 50% reductions in hospital-acquired infection rates. The pre-pandemic EBD case for single-room design has been substantially strengthened by the pandemic evidence.

Fourth, Systemic Resilience interventions, particularly hospital-city spatial integration and digital infrastructure embedding, carry the most significant policy implications for the next generation of healthcare-built environments. Their evidence quality is the highest of the three tiers, suggesting disproportionate returns on research and implementation investment in this category.

Fifth, the geographic concentration of the reviewed literature in high-income countries is a significant gap that must be addressed for the post-pandemic hospital design literature to serve as a basis for globally equitable architectural guidance.

Recommendations

For Regulatory Bodies and Health Authorities

National and international healthcare design regulatory bodies should revise post-pandemic design guidance frameworks to reflect the evidence-quality hierarchy established in this review, weighting Tier 2 and Tier 3 intervention guidance more heavily than Tier 1 guidance relative to current practice. Specifically, the single-room design evidence base is now sufficiently robust to support its adoption as a baseline standard for new acute hospital construction rather than an aspirational recommendation.

For Research Funders

Funding bodies should prioritize longitudinal comparative studies of Tier 3 interventions, particularly decentralized utility infrastructure and campus-scale zoning strategies, where the evidence base is strongest but the most significant gaps in outcome data exist. This priority should be framed explicitly as a response to the geographic concentration of the existing review corpus: the underrepresentation of Global South contexts documented in Section 5.3 and Conclusion 5 of this review reflects a structural gap in the international research base that cannot be addressed without targeted investment in national research bodies across underrepresented regions. Funders including, but not limited to, African national health research institutions such as the Nigerian Ministry of Health and the Nigerian Centre for Disease Control and Prevention (NCDC), along with equivalent bodies across Sub-Saharan Africa, South and Southeast Asia, and Latin America, should be specifically supported to develop context-appropriate research programmes.

For Practicing Architects

Architects engaged in post-pandemic hospital design should approach the abundant Tier 1 literature with calibrated skepticism, recognizing that volume of publication does not correspond to strength of evidence. Design decisions regarding permanent spatial configuration, room dimensions, servicing infrastructure, zoning strategies, should be grounded in the higher-quality Tier 2 and Tier 3 evidence base, supplemented by Tier 1 case reports only for decisions regarding deployable and reversible elements.

For Academic Institutions

Architecture programmes and health design research centres should develop methodological capacity for post-occupancy evaluation and building performance simulation in clinical settings, given the role these methods play in generating higher-quality evidence in Tiers 2 and 3. The modified MMAT framework developed in this review offers a starting point for quality appraisal in design research contexts that do not fit standard clinical evidence hierarchies.

For Facility Managers and Hospital Operators

Facility managers should treat pandemic-period spatial adaptations as an opportunity for systematic post-occupancy documentation, producing the comparative data that the literature currently lacks. Structured documentation of operational outcomes under different spatial configurations, particularly for HVAC system performance, single-room versus multi-bed bay infection rates, and digital infrastructure resilience, will constitute the longitudinal evidence base those future systematic reviews require.

For healthcare facility regulators and standards bodies: The Facility Guidelines Institute, NHS England, the Australasian Health Facility Guidelines, and equivalent national standards bodies should incorporate the three-tier taxonomy as a framework for updating pandemic-preparedness provisions in healthcare facility design guidelines, establishing minimum embedded flexibility standards, single-room provision, convertible room infrastructure, universal bay dimensional standards, as regulatory requirements for all new acute hospital construction and major refurbishment programmes.

For hospital design research funders: Research commissioners including, The Nigerian Ministry of Health, Nigerian Centre for Disease control and Prevention (NCDC), and equivalent national research bodies should prioritise funding for prospective, comparative post-occupancy evaluation studies of pandemic-adapted hospitals, with a specific requirement for standardized outcome measurement enabling cross-study meta-analysis. The current dominance of case-report methodology can only be corrected by research funding structures rewarding comparative empirical rigour over publication speed.

For practicing architects: Design teams commissioned to develop new acute hospital facilities or major refurbishments should treat the evidence-quality hierarchy established by this review as a design decision tool, prioritizing investment in Embedded Flexibility provisions, single rooms, convertible ICU capacity, adaptable services infrastructure, over Ephemeral Adaptability provisions on the grounds that the former have a substantially stronger evidence base and provide permanent rather than temporary clinical quality improvement.

For academic institutions: Schools of architecture that has curriculum which covers healthcare design, should establish research programmes specifically addressing underrepresented geographic regions and intervention tiers identified in this review, Collaborative research networks spanning high-income and lower-income country institutions should be developed to address the geographic imbalance in the current evidence base.

For hospital facility managers and clinical leaders: post-occupancy evaluation of pandemic-adapted spaces should be commissioned as a standard institutional process following any significant emergency adaptation, using validated instruments generating comparable

data across facilities. The gap between the volume of pandemic adaptation literature and the scarcity of rigorous outcome data reflects the absence of institutional cultures of systematic spatial evaluation, a deficiency that facility managers are uniquely positioned to address.

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