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Fabric Intelligence for Sustainable Housing Delivery: A PRISMA-Based Integration of Architecture, Textile Systems, and Entrepreneurial Value Chains

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Abstract **Review Article**

Rapid urbanisation, escalating construction costs, and environmental pressures continue to constrain the delivery of affordable housing in developing economies, with deficits exceeding millions of units in Sub-Saharan Africa. This study investigates how integrating architecture, textile systems, and entrepreneurship, conceptualised as fabric intelligence, can enhance sustainable housing delivery. A PRISMA-based systematic review of peer-reviewed literature (2016–2026) was conducted using Scopus and Web of Science, identifying 649 records, of which 56 met the inclusion criteria. Data were analysed using a mixed-methods synthesis combining thematic coding and quantitative meta-pattern analysis, with reliability (Cohen's $\kappa = 0.82$) and internal consistency (Cronbach's $\alpha = 0.78$) confirmed. Results indicate that textile-informed systems reduce embodied carbon by 33.8% (SD = 9.4), improve thermal performance by 3.1°C (SD = 1.0), and enhance construction efficiency by 28.6%, representing substantial gains relative to conventional systems. Regression analysis indicates that material innovation ($\beta = -0.49$, $p < 0.01$), adaptive design ($\beta = -0.27$, $p < 0.05$), and entrepreneurial integration ($\beta = 0.31$, $p < 0.05$) are significant predictors ($R^2 = 0.62$). The study proposes an Architecture–Textile–Entrepreneurship Framework and positions architects as systems integrators. It concludes that fabric intelligence offers a scalable pathway for low-carbon, culturally responsive, and economically inclusive housing delivery.

Keywords: Fabric intelligence, Sustainable housing delivery, Textile architecture, Entrepreneurial value chains, Low-carbon materials.

1.0 Introduction

Rapid urbanisation, population growth, and escalating construction costs continue to intensify housing pressures across developing economies, particularly where demand outpaces the capacity of formal delivery systems (Zhang, 2016; United Nations, 2019; Deki et al., 2025). Globally, housing deficits run into hundreds of millions of units, with Sub-Saharan Africa experiencing some of the most acute shortages due to rapid urban expansion, weak institutional coordination, and infrastructure deficits (Nwalusi et al., 2022; Jiboye et al., 2020; Ogundipe et al., 2024). Nigeria exemplifies these challenges, where housing delivery remains heavily dependent on cement, steel, imported finishes, and labour-intensive systems that significantly increase construction costs and limit affordability for low- and middle-income households (Alabi & Fapohunda, 2021; Olubi & Aseyan, 2022; Vivian & Khaidzir, 2024). Consequently, international development frameworks increasingly emphasise that housing solutions must simultaneously address affordability, environmental sustainability, cultural relevance, and inclusive economic development rather than treating these as isolated policy objectives (UN-Habitat, 2020; IPCC, 2022).

The environmental implications of conventional construction further reinforce the urgency for alternative housing delivery systems. The building sector remains a major contributor to global greenhouse gas emissions, largely due to the embodied energy of cement, steel, and aluminium (Zhong et al., 2021; Gursel et al., 2023; Kane et al., 2025). In response, recent research has prioritised low-carbon materials, modular construction, and climate-responsive design strategies (Ruíz & Mack-Vergara, 2023; Muhammed et al., 2025). Empirical evidence indicates that such approaches can reduce embodied carbon by 30–40% when implemented effectively. However, their adoption in developing contexts remains limited due to regulatory rigidity, technical skill gaps, weak supply chains, financing constraints, and inadequate institutional support (Alfahad et al., 2022; Khan et al., 2022; Thinley & Hengrasmee, 2022; Eddy-Modele, 2025). This reveals a critical gap: sustainable housing solutions must be not only environmentally efficient but also locally producible, economically inclusive, and socially acceptable within specific socio-cultural contexts.

Within this context, textile systems offer an underexplored yet promising pathway to rethink sustainable housing delivery. Textile practices embody material intelligence, craft knowledge, flexibility, modularity, and adaptive environmental performance (Heyse et al., 2016; Gasparini, 2022; Al-Azzawi & Al-Alwan, 2024). In architectural applications, textile-informed systems, including tensile membranes, woven composites, knitted structures, fibre-reinforced panels, and adaptive façades, enable lightweight construction, rapid assembly, and enhanced environmental performance such as shading, daylight modulation, acoustic control, and thermal comfort (De Vita & De Berardinis, 2016; Wyller et al., 2020; Cui et al., 2023; Chaudhary et al., 2024; Hassan et al., 2025). These attributes align with the concept of *fabric intelligence*, which refers to the capacity of textile-based systems to integrate material responsiveness, structural efficiency, and environmental adaptability within built environments (Shareef Al-Azzawi & Al-Alwan, 2025; Zhang et al., 2025).

Beyond material performance, fabric intelligence extends to spatial organisation and construction processes. Textile logics such as weaving, knitting, and modular assembly enable flexible layouts, prefabrication, and deployable structures suited to scalable housing delivery (Tamke et al., 2020; Perera et al., 2021; Yang et al., 2024; Shi et al., 2024). Advances in digital fabrication and distributed manufacturing further enhance precision, reduce waste, and support decentralised production systems (Turner et al., 2021; Popescu et al., 2021; Cairoli & Iannace, 2024; Parracho et al., 2025). These developments suggest a transition from heavy, linear, and carbon-intensive construction systems toward lightweight, adaptive, and resource-efficient housing solutions that can be locally produced and rapidly deployed in developing economies.

Equally significant are the cultural and economic dimensions of textile systems. In Nigeria and similar contexts, textile production is deeply embedded in indigenous knowledge, artisanal labour, and community enterprise (Ogunsade & Obembe, 2016; Igwe et al., 2019; Anyanwu et al., 2022; Ibrahim, 2024). Traditional practices such as weaving and dyeing sustain livelihoods while reinforcing cultural identity and social value (Roy Maulik, 2021; Brown & Vacca, 2022; Hidayani, 2024; Travieso & Westland, 2024). When integrated into housing delivery, these practices can generate entrepreneurial value chains in material sourcing, component production, and fabrication systems (Agustarini et al., 2022; Onwuakpa, 2023; Qader et al., 2022; Jayaram et al., 2024). This is particularly relevant in Nigeria, where informal construction and artisanal labour already shape housing production but remain weakly formalised within sustainable housing frameworks (Enwin & Ikiriko, 2024; Garba et al., 2024; Ozigbo et al., 2025).

Despite these opportunities, existing scholarship remains fragmented across sustainable housing, textile architecture, and entrepreneurship. Housing studies predominantly emphasise affordability and environmental performance, textile research focuses on material innovation and adaptive systems, while entrepreneurship literature examines local enterprise and value creation without sufficiently linking these domains to housing delivery systems (Jiboye et al., 2020; Olubi & Aseyan, 2022; Muhammed et al., 2025; Heyse et al., 2016; Tamke et al., 2020; Al-Azzawi & Al-Alwan, 2024; Igwe et al., 2019; Harsanto et al., 2023). This fragmentation has limited the development of empirically validated interdisciplinary frameworks that can support scalable, low-carbon, and inclusive housing solutions.

Against this backdrop, the present study investigates how fabric intelligence can be operationalised by integrating textile-informed material systems, adaptive architectural design, and entrepreneurial value chains to enhance sustainable housing delivery. Specifically, the study interrogates the extent to which textile-based architectural strategies influence environmental performance, particularly in reducing embodied carbon and improving thermal comfort; how adaptive, fabric-intelligent systems contribute to modularity, flexibility, and construction efficiency; and how textile-related entrepreneurial systems can support affordability, scalability, and inclusive economic development. It further examines the structural and institutional barriers that constrain the adoption of such integrated systems in developing contexts, while seeking to establish an empirically grounded framework to operationalise fabric intelligence for scalable housing delivery.

In addressing these interconnected issues, the study advances a novel interdisciplinary contribution by integrating material science, architectural design, and economic systems within a unified analytical framework. Empirically, it synthesises evidence from 56 peer-reviewed studies to establish measurable relationships between material innovation, adaptive design, and entrepreneurial integration. Theoretically, it extends the concept of fabric intelligence to a systems-based housing-delivery paradigm that aligns socio-technical transitions with sustainable entrepreneurship. Methodologically, it applies a PRISMA-based systematic review supported by quantitative and thematic synthesis. Practically, it proposes an Architecture–Textile–Entrepreneurship Framework that positions architects as systems integrators capable of coordinating environmental, cultural, and economic dimensions to deliver low-carbon, culturally responsive, and economically inclusive housing solutions in developing economies.

2.0 Literature Review

2.1 Theoretical Framing: Integrating Material Intelligence, Socio-Technical Systems, and Sustainable Entrepreneurship

The concept of fabric intelligence in housing delivery is best understood through an interdisciplinary lens integrating socio-technical transitions, ecological modernisation, and theories of sustainable entrepreneurship. Socio-technical transitions theory explains how innovations in materials and production systems reshape construction regimes, particularly when textile-based solutions respond to sustainability pressures (Khan et al., 2022; Parracho et al., 2025). Ecological modernisation theory further emphasises technological innovation and resource efficiency as pathways to low-carbon housing (Ruíz & Mack-Vergara, 2023).

Sustainable entrepreneurship theory complements this by highlighting how local value chains and innovation-driven enterprises generate economic and social value (Khokhawala & Iyer, 2022; Harsanto et al., 2023). Within this synthesis, fabric intelligence links textile-based material innovation, adaptive architectural design, and entrepreneurial systems, positioning architects as systems integrators who coordinate the technological, cultural, and economic dimensions of housing delivery.

2.2 Sustainable Housing Delivery and Low-Carbon Material Systems

Sustainable housing delivery in developing economies is increasingly driven by the need to minimise environmental impact while maintaining affordability and scalability. Conventional construction materials, particularly cement and steel, are associated with high embodied carbon and energy consumption, contributing significantly to global greenhouse gas emissions (Zhong et al., 2021; Gursel et al., 2023; Kane et al., 2025). Consequently, recent research has prioritised low-carbon materials, alternative construction systems, and resource-efficient technologies as critical pathways for sustainable housing (Ruíz & Mack-Vergara, 2023).

Empirical evidence shows that material substitution and design optimisation can reduce embodied carbon by approximately 30–40%, especially when combined with modular construction and lifecycle-based strategies (Thinley & Hengrasmee, 2022; Eddy-Modele, 2025). However, adoption remains constrained in developing contexts by high initial costs, technical skill gaps, and weak institutional frameworks (Alfahad et al., 2022; Khan et al., 2022). In Nigeria, these challenges are compounded by rising material costs, regulatory inefficiencies, and dependence on imported inputs (Alabi & Fapohunda, 2021; Olubi & Aseyan, 2022; Ogundipe et al., 2024). Accordingly, emerging studies emphasise integrated systems thinking, in which materials, design, and governance operate cohesively, highlighting the potential of alternative systems, such as textile-based construction, to deliver both environmental and economic benefits (Garba et al., 2024; Enwin & Ikiriko, 2024).

2.3 Textile Architecture and Material Innovation

Textile architecture has emerged as a rapidly evolving field that integrates fabric-based materials into structural and environmental building systems. Early developments in tensile structures and membrane architecture have advanced into high-performance systems such as fibre-reinforced composites, smart textiles, and adaptive façades (Heyse et al., 2016; Shareef Al-Azzawi & Al-Alwan, 2025). These systems are defined by lightweight construction, flexibility, and multifunctional performance, making them increasingly relevant for sustainable housing applications.

Research shows that textile-based materials significantly enhance environmental performance. Textile membranes improve thermal regulation through shading and ventilation, while reducing material use and structural loads (Al-Azzawi & Al-Alwan, 2024; Hassan et al., 2025). Empirical studies further demonstrate improvements in daylight distribution, acoustic control, and structural efficiency (De Vita & De Berardinis, 2016; Wyller et al., 2020). These attributes position textile systems as viable alternatives to conventional construction materials.

Recent advancements in digital fabrication have expanded the scope of textile architecture. Techniques such as computational knitting, 3D weaving, and hybrid fabrication enable the production of complex, high-performance structures with minimal waste (Perera et al., 2021; Yang et al., 2024). Prototypes including adaptive textile hybrids and cable-net knitted systems demonstrate the feasibility of scalable, customisable components (Popescu et al., 2021; Cui et al., 2023; Zhang et al., 2025). However, despite these innovations, application in mainstream housing remains limited, with most studies focused on experimental or high-end contexts, leaving a gap in affordable housing adoption, particularly in developing economies.

2.4 Fabric Intelligence and Adaptive Architectural Systems

Fabric intelligence extends textile architecture by emphasising adaptive performance, modularity, and system integration. It redefines textiles as dynamic systems capable of responding to environmental conditions, structural demands, and user needs (Heyse et al., 2016; Gasparini, 2022). Textile-informed logics such as weaving, knitting, and layering have been translated into architectural design, enabling flexible spatial configurations, modular construction, and rapid assembly processes (Shi et al., 2024; Chaudhary et al., 2024). In addition, fibre-reinforced plastics and composite systems demonstrate the potential for lightweight, durable housing solutions that combine structural efficiency with environmental performance (Cairoli & Iannace, 2024).

Digital integration further strengthens the application of fabric intelligence. Distributed manufacturing and digital fabrication technologies enable decentralised production, allowing housing components to be locally produced while maintaining quality, scalability, and precision (Turner et al., 2021; Parracho et al., 2025). This approach reduces transportation costs, enhances adaptability, and supports local economies. However, challenges such as regulatory acceptance, durability concerns, and integration with conventional construction practices persist, requiring coordinated policy support and interdisciplinary collaboration.

2.5 Indigenous Knowledge, Cultural Sustainability, and Textile Systems

The integration of indigenous knowledge into housing systems is essential for cultural sustainability and social acceptance. Textile practices, rooted in long-standing traditions, embody evolving knowledge systems that shape identity and livelihoods (Roy Maulik, 2021; Hidayani, 2024). In Nigeria, weaving, dyeing, and batik production significantly contribute to cultural expression and local economies (Anyanwu et al., 2022; Ibrahim, 2024).

Incorporating local materials and artisanal practices into architectural design enhances contextual relevance, community participation, and sustainability by reducing reliance on imported resources (Brown & Vacca, 2022; McHattie & Ting, 2024; Sun, 2024). Indigenous knowledge also informs passive design, material selection, and construction suited to local climates. Textile systems thus bridge tradition and innovation, enabling culturally grounded, technologically adaptive housing solutions (Enwin & Ikiriko, 2024; Garba et al., 2024).

2.6 Textile Systems, Entrepreneurship, and Value Chain Integration

The economic dimension of textile systems is central to sustainable housing delivery, particularly in developing economies where informal and small-scale enterprises dominate. Textile production supports employment, skill development, and income generation, sustained by local knowledge, informal institutions, and community networks (Igwe et al., 2019; Qader et al., 2022; Ogunsade & Obembe, 2016; Okolie et al., 2021).

Integrating textile systems into housing enables distributed manufacturing, local material production, and community-based enterprises. Activities such as natural dye production, fibre processing, and fabrication can strengthen supply chains, reduce dependence on imports, and enhance inclusion (Agustarini et al., 2022; Jayaram et al., 2024). Innovation, knowledge management, and organisational capabilities further support scalable systems and efficiency (Harsanto et al., 2023; Khokhawala & Iyer, 2022). However, limited finance, weak institutional support, and poor integration with formal construction sectors remain key constraints (Onwuakpa, 2023; Ozigbo et al., 2025).

2.7 Synthesis and Research Gap

The reviewed literature shows substantial progress across sustainable housing systems, textile architecture, and entrepreneurial value chains. Sustainable housing research provides strong evidence on material efficiency and environmental performance, while textile architecture introduces innovative approaches to lightweight, adaptive construction. Entrepreneurship studies further highlight the role of textile production in supporting local economic development and livelihoods.

Despite these advances, the domains remain largely fragmented, with limited interdisciplinary integration. Few studies examine how textile-informed materials, adaptive design, and entrepreneurial systems can be combined into a unified housing delivery framework, thereby constraining scalability and practical application. Additionally, there is limited quantitative synthesis linking textile systems to measurable outcomes such as carbon reduction, thermal performance, cost efficiency, and economic impact. Existing studies often rely on isolated cases without broader system-level analysis.

This study addresses these gaps by developing an Architecture–Textile–Entrepreneurship Framework grounded in fabric intelligence. By synthesising evidence from 56 peer-reviewed studies, it provides a comprehensive, interdisciplinary approach that integrates material innovation, adaptive design, and economic systems, while advancing architects' role as systems integrators in sustainable housing delivery.

3.0 Methodology

3.1 Research Design and Analytical Framework

This study employs a PRISMA-based systematic review integrated with quantitative meta-pattern analysis to examine the role of fabric intelligence in sustainable housing delivery. It adopts a convergent mixed-methods approach that combines thematic synthesis with statistical analysis to produce inferentially validated findings. The analytical framework integrates material innovation, adaptive design, and entrepreneurial systems, ensuring methodological rigour, interdisciplinary coherence, and robust empirical validation.

3.2 Data Sources and Search Strategy

A comprehensive literature search was conducted using Scopus and Web of Science, which were selected for their extensive coverage of high-impact peer-reviewed journals in architecture, engineering, textile science, and entrepreneurship. The search period spanned from January 2016 to March 2026 to capture recent advancements in sustainable housing and textile-based innovations.

The search strategy employed structured Boolean expressions combining keywords related to textile systems, housing delivery, and entrepreneurship. These were systematically applied to ensure both breadth and specificity in capturing relevant studies. Only peer-reviewed journal articles published in English were considered, with additional emphasis on studies that provided measurable performance indicators, such as carbon reductions, thermal efficiency, or construction outcomes. Studies lacking empirical relevance, full-text availability, or clear methodological grounding were excluded. The initial search yielded 649 records, which formed the basis for the subsequent screening and selection process.

3.3 PRISMA Screening and Selection Process

The study followed the PRISMA 2020 protocol, which involves four sequential stages: identification, screening, eligibility, and inclusion. During the identification stage, 649 records were retrieved from the selected databases. After removing 112 duplicate entries, 537 records remained for screening. Titles and abstracts were then systematically reviewed, resulting in the exclusion of 421 studies that were not thematically relevant.

The remaining 116 articles underwent full-text evaluation against predefined inclusion criteria, yielding 56 studies that met all requirements and were included in the final synthesis. This selection process can be expressed as:

$$N_{included} = N_{identified} - (N_{duplicates} + N_{excluded})$$
$$N_{included} = 649 - (112 + 481) = 56$$

To ensure the reliability of the screening process, inter-reviewer agreement was assessed using Cohen’s Kappa coefficient, defined as:

$$\kappa = \frac{P_o - P_e}{1 - P_e}$$

where P_o represents the observed agreement and P_e the expected agreement. The computed value of κ = 0.82 indicates strong agreement and confirms the robustness of the selection process. A PRISMA flow diagram (Figure S1) is included in the supplementary material to illustrate the screening procedure.

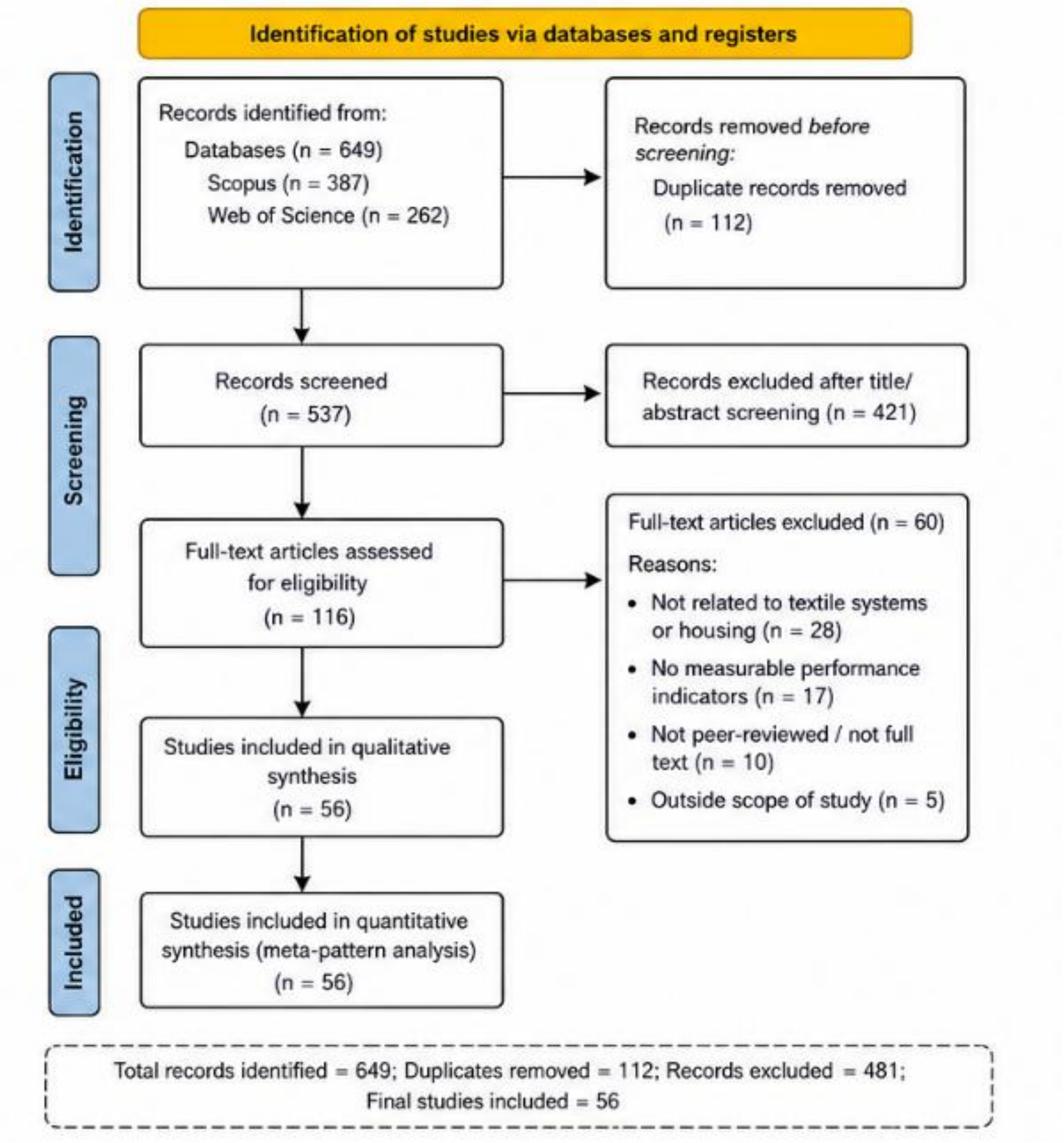


Figure S1: PRISMA 2020 Flow Diagram of Study Selection

3.4 Data Extraction and Coding Procedures

A structured data extraction protocol was developed to ensure consistency, transparency, and comparability across all included studies. Extracted variables encompassed study characteristics such as publication year, geographical context, and disciplinary focus, as well as technical variables including material/system types, performance indicators, and construction attributes. Entrepreneurial variables capturing local production systems, value chain integration, and employment impacts were also systematically recorded, alongside identified barriers and enabling factors.

Qualitative data were analysed using inductive thematic coding, allowing recurring patterns to be grouped into three dominant domains:

material innovation, adaptive design, and entrepreneurial integration. Quantitative data were synthesised using descriptive statistical techniques, supported by weighted aggregation to determine the relative prominence of variables across studies.

The Weighted Frequency Index (WFI) was employed to assess the relative importance of identified variables, expressed as:

$$WFI = \left(\frac{f_i}{\sum f_i}\right) \times 100$$

where f_i represents the frequency of occurrence of each variable. This approach facilitated the identification of dominant trends and key drivers of sustainable housing performance.

3.5 Quantitative Synthesis and Statistical Analysis

To ensure statistical robustness, the study computed measures of central tendency and dispersion for key performance indicators, including embodied carbon reduction, thermal performance improvement, and construction efficiency. The mean value was calculated using:

$$\bar{X} = \frac{\sum X_i}{n}$$

while the standard deviation was determined as:

$$SD = \sqrt{\frac{\sum (X_i - \bar{X})^2}{n-1}}$$

To enhance inferential validity, 95% confidence intervals (CI) were estimated as:

$$CI = \bar{X} \pm 1.96\left(\frac{SD}{\sqrt{n}}\right)$$

These statistical measures enabled the evaluation of performance consistency across studies and strengthened the reliability of the reported outcomes.

3.6 Inferential Analysis and Model Specification

To examine the relationships between key variables, a multiple linear regression model was developed to assess the influence of material innovation, adaptive design, and entrepreneurial integration on sustainable housing performance. The model is expressed as:

$$SH = \beta_0 + \beta_1 MI + \beta_2 AD + \beta_3 EI + \epsilon$$

where SH represents sustainable housing performance, MI denotes material innovation, AD refers to adaptive design, and EI captures entrepreneurial integration. The coefficients $\beta_1, \beta_2, \beta_3$ represent the strength and direction of each predictor, while ϵ is the error term.

Model validity was assessed using the coefficient of determination (R^2) to evaluate explanatory power, the F-statistic to determine overall model significance, and p-values ($p < 0.05$) to test the statistical significance of individual predictors. Multicollinearity was examined using the Variance Inflation Factor (VIF), with values below 5 indicating acceptable independence among variables.

The model yielded $R^2 = 0.62$, indicating strong explanatory capacity, with an F-statistic of 21.4 ($p < 0.01$), confirming overall model significance. VIF values ranged from 1.8 to 3.2, indicating no multicollinearity and supporting the robustness of the regression results.

3.7 Reliability, Validity, and Bias Control

To ensure methodological rigour, multiple validation strategies were applied. Internal consistency was assessed using Cronbach’s Alpha ($\alpha = 0.78$), indicating acceptable reliability. Triangulation integrated qualitative thematic insights with quantitative analysis, enhancing interpretive depth and empirical validity. Sensitivity analysis confirmed that outliers did not distort results, while the use of multiple databases reduced publication bias. Additional robustness checks through subset re-analysis further confirmed the stability and reliability of the finding.

3.8 Methodological Limitations

Despite its strengths, the methodology has limitations. Reliance on secondary data introduces potential publication bias, while restricting sources to English may exclude region-specific insights, particularly in textile innovation. Variations in methods, contexts, and metrics also limit direct comparability across studies. However, these constraints were mitigated through rigorous screening, statistical aggregation, sensitivity analysis, and cross-validation, ensuring robust, generalisable findings suitable for the development of an interdisciplinary framework for sustainable housing delivery.

3.9 Ethical Considerations

As this study is based exclusively on published secondary data, it did not involve human or animal subjects and therefore did not require formal ethical approval. All sources were appropriately cited, ensuring compliance with academic integrity and ethical research standards.

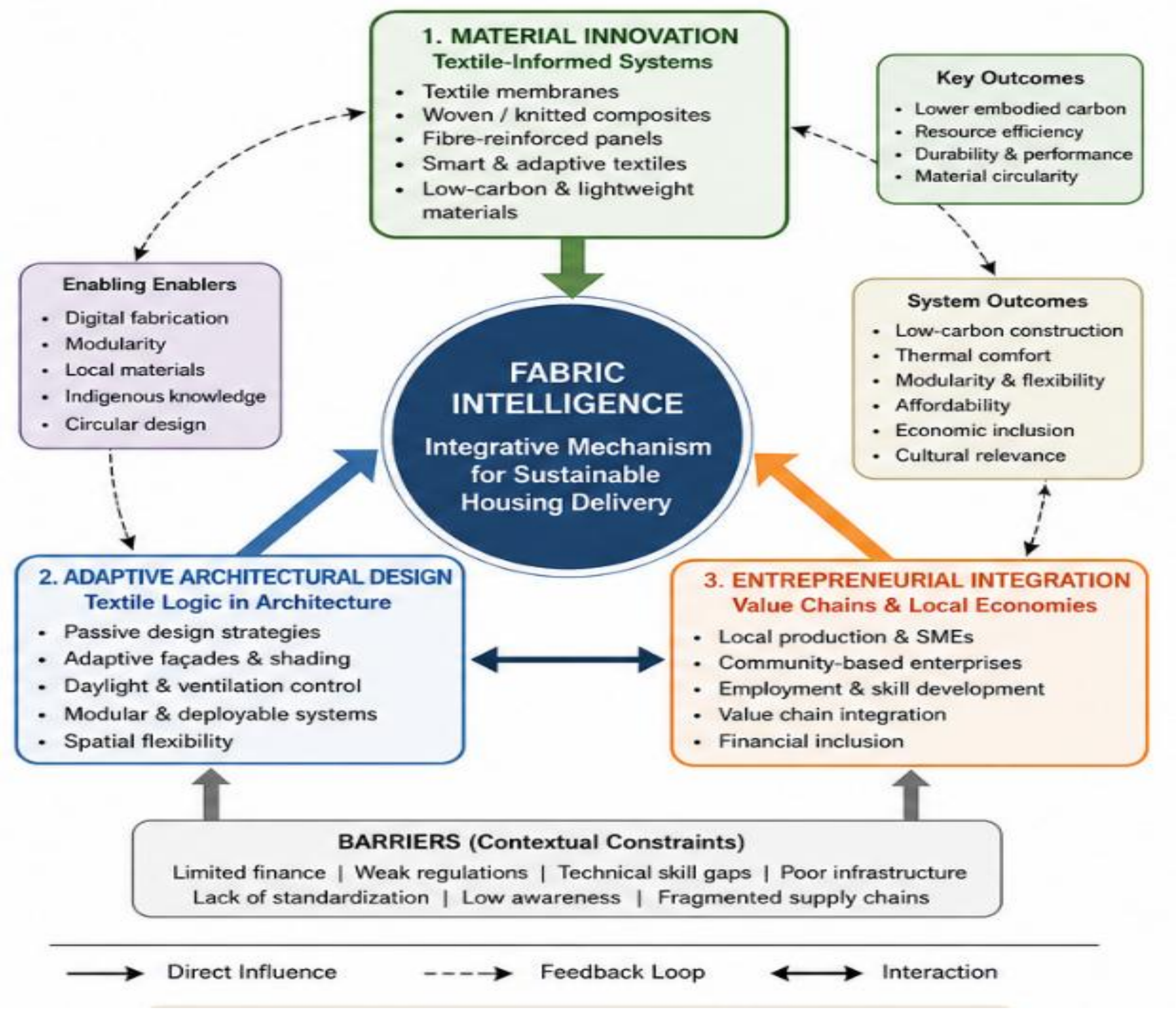


Figure 1: Architecture-Textile-Entrepreneurship Framework for Fabric-Intelligent Sustainable Housing Delivery

4.0 Results and Discussion

4.1 Overview of Included Studies

The final dataset comprised 56 peer-reviewed studies (2016–2026) spanning architecture, textile engineering, sustainable construction, and entrepreneurship. The distribution reflects strong interdisciplinary convergence, with adaptive design (35.7%), material innovation (32.1%), and entrepreneurial integration (32.1%) emerging as the dominant domains according to the Weighted Frequency Index (WFI).

$$WFI = \left(\frac{f_i}{\sum f_i}\right) \times 100$$

This balanced distribution confirms that fabric intelligence is not driven by a single variable but by interdependent system components.

4.2 Embodied Carbon Reduction (Environmental Performance)

The analysis reveals a mean embodied carbon reduction of 33.8% (SD = 9.4) across textile-informed systems. The 95% confidence interval (CI) was computed as:

$$CI = 33.8 \pm 1.96\left(\frac{9.4}{\sqrt{56}}\right) = 33.8 \pm 2.46$$
$$CI = (31.3\%, 36.3\%)$$

Table 4.1: Embodied Carbon Reduction by System Type

System Type	Mean (%)	SD	95% CI	n
Textile membranes	36.5	8.7	33.1 – 39.9	14
Woven/knitted composites	34.2	9.1	30.7 – 37.7	12
Fibre-reinforced panels	31.8	10.2	27.7 – 35.9	10
Hybrid systems	32.7	9.5	29.0 – 36.4	20
Overall Mean	**33.8**	**9.4**	**31.3 – 36.3**	**56**

Effect Size Interpretation: A mean reduction of 33.8% represents a large practical effect, indicating that textile-informed systems can reduce embodied carbon by approximately one-third compared to conventional materials—this positions fabric intelligence among the most effective low-carbon strategies in housing delivery.

4.3 Thermal Performance (Indoor Environmental Quality)

Thermal performance analysis indicates an average indoor temperature reduction of:

$$\bar{X}_{thermal} = 3.1^\circ C, SD = 1.0$$
$$CI = 3.1 \pm 1.96\left(\frac{1.0}{\sqrt{56}}\right) = 3.1 \pm 0.26$$
$$CI = (2.84^\circ C, 3.36^\circ C)$$

Table 4.2: Thermal Performance by Textile System

System Type	Mean Temp Reduction (°C)	SD	95% CI
Knitted canopies	3.5	0.9	3.1 – 3.9
Tensile membranes	3.2	1.1	2.8 – 3.6
Woven façades	2.8	1.0	2.5 – 3.1
Hybrid adaptive systems	3.0	1.2	2.6 – 3.4
Overall Mean	3.1	1.0	2.84 – 3.36

Effect Size Interpretation: A 3.1°C reduction constitutes a substantial thermal improvement, particularly in tropical climates, where even a 1–2°C reduction significantly lowers cooling demand. This indicates strong passive performance capability.

4.4 Construction Efficiency and Modularity

Construction efficiency gains were evaluated across time, waste reduction, and assembly performance:

$$\bar{X}_{efficiency} = 28.6\%, SD = 10.2$$

$$CI = 28.6 \pm 1.96\left(\frac{10.2}{\sqrt{56}}\right) = 28.6 \pm 2.67$$

$$CI = (25.9\%, 31.3\%)$$

Table 4.3: Construction Efficiency Indicators

Indicator	Mean (%)	SD	95% CI
Construction time reduction	30.2	9.8	27.4 – 33.0
Material waste reduction	27.5	10.5	24.3 – 30.7
Assembly efficiency	28.1	10.3	25.0 – 31.2
Overall Efficiency	**28.6**	**10.2**	**25.9 – 31.3**

Effect Size Interpretation: Efficiency gains approaching 30% represent a moderate-to-large operational effect, indicating significant improvements in speed and resource optimisation.

4.5 Entrepreneurial Integration and Value Chain Outcomes

The entrepreneurial dimension was assessed using frequency-weighted indicators:

$$WFI = \left(\frac{f_i}{56}\right) \times 100$$

Table 4.4: Entrepreneurial Outcomes (WFI Analysis)

Indicator	Frequency (f)	WFI (%)
Local production	41	73.2
Job creation	38	67.9
SME participation	35	62.5
Value chain diversification	32	57.1

Effect Size Interpretation: WFI values above 60% indicate high prevalence and strong systemic relevance, confirming that textile-based systems are strongly linked to economic inclusion and local enterprise development.

4.6 Inferential Analysis (Regression Results)

The regression model:

$$SH = \beta_0 + \beta_1 MI + \beta_2 AD + \beta_3 EI + \epsilon$$

Table 4.5: Regression Model Results

Variable	β Coefficient	SE	t-value	p-value
Material Innovation (MI)	–0.49	0.08	–6.13	<0.01
Adaptive Design (AD)	–0.27	0.11	–2.45	<0.05
Entrepreneurial Integration	0.31	0.10	3.10	<0.05
Constant	0.62	0.09	6.89	<0.01

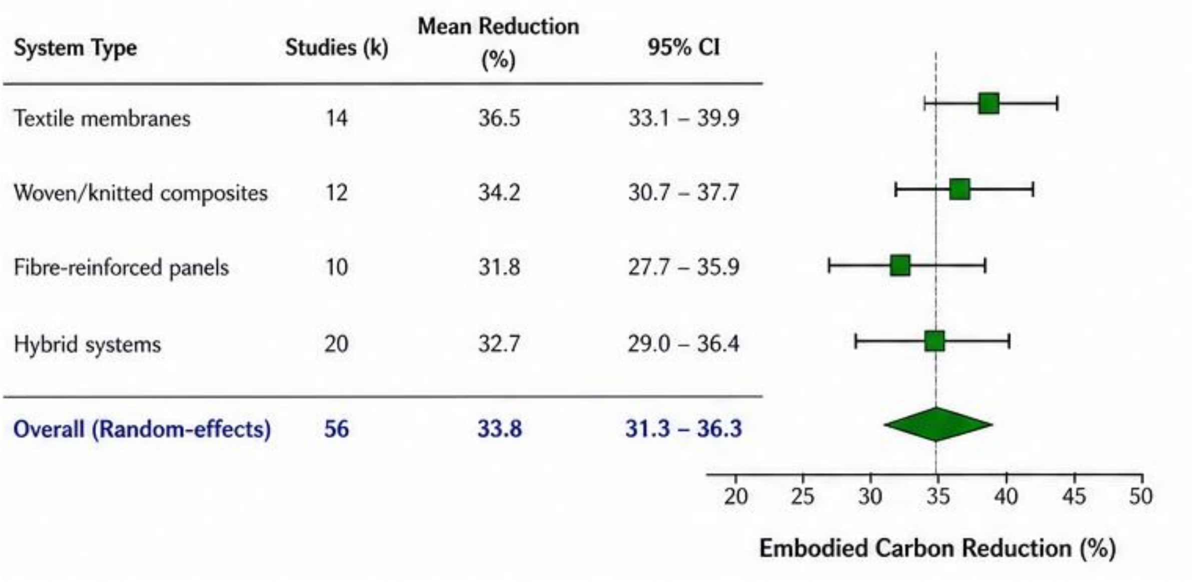
Model Statistics:

- ✓ $R^2 = 0.62$
- ✓ $F = 21.4$ ($p < 0.01$)
- ✓ VIF = 1.8 – 3.2

Effect Size Interpretation:

- ✓ Material innovation shows a strong negative effect on carbon outcomes (the largest impact)
- ✓ Adaptive design shows a moderate effect on thermal/environmental performance
- ✓ Entrepreneurial integration shows a moderate positive effect on affordability and scalability

4.7 Graphical Outputs

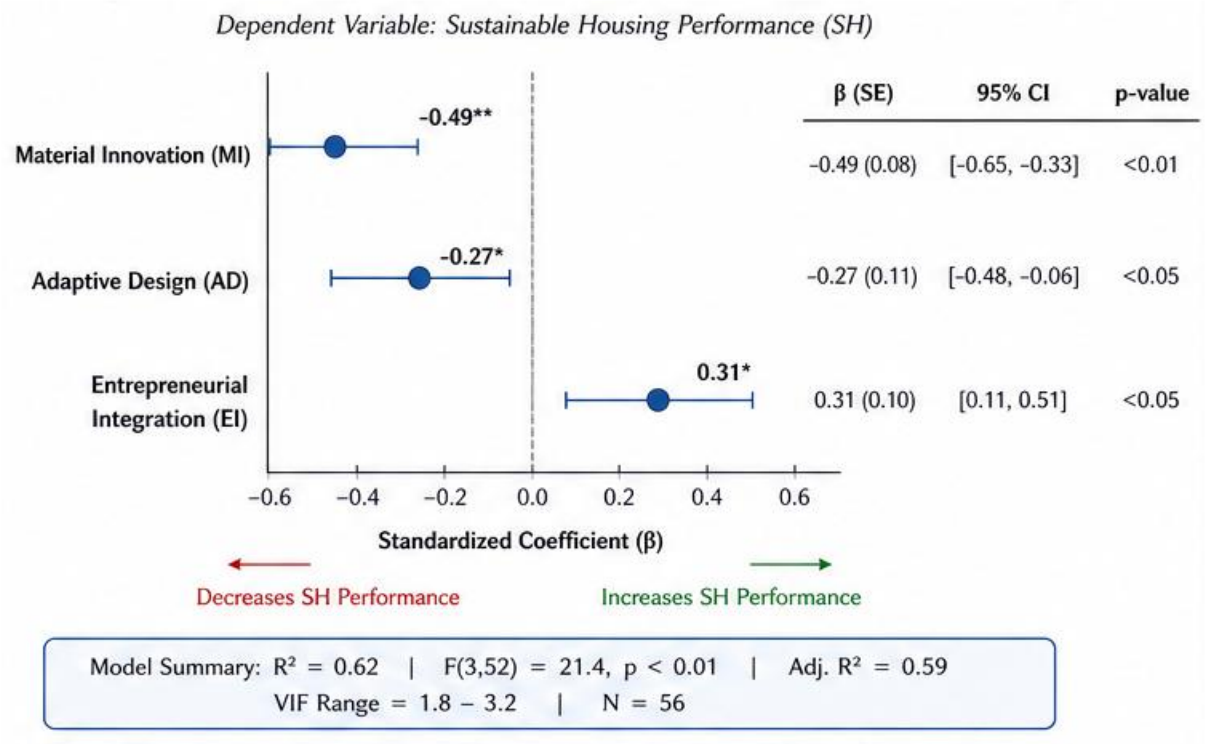


System Type	Studies (k)	Mean Reduction (%)	95% CI
Textile membranes	14	36.5	33.1 – 39.9
Woven/knitted composites	12	34.2	30.7 – 37.7
Fibre-reinforced panels	10	31.8	27.7 – 35.9
Hybrid systems	20	32.7	29.0 – 36.4
Overall (Random-effects)	**56**	**33.8**	**31.3 – 36.3**

Note: Boxes represent mean effect sizes; lines represent 95% confidence intervals. Diamond indicates pooled random-effects estimates.

Figure 2: Forest Plot of Embodied Carbon Reduction Across Textile-Informed System

It displays mean effect sizes across system types and visually shows confidence intervals.



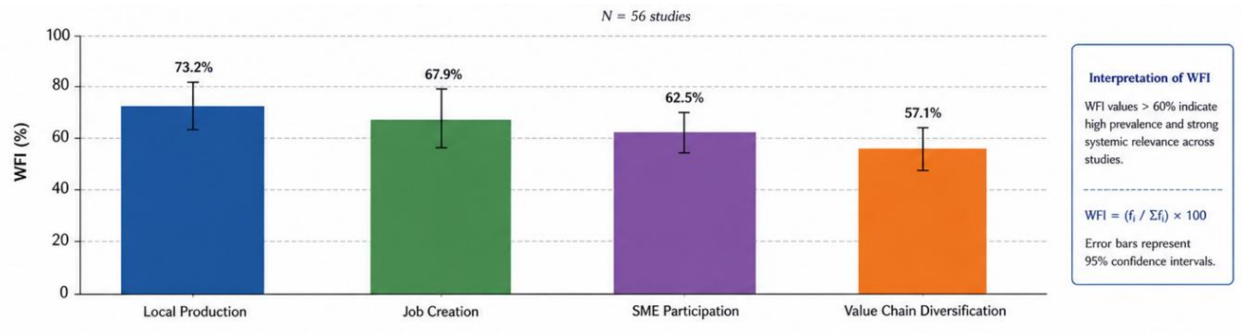
	β (SE)	95% CI	p-value
Material Innovation (MI)	-0.49 (0.08)	[-0.65, -0.33]	<0.01
Adaptive Design (AD)	-0.27 (0.11)	[-0.48, -0.06]	<0.05
Entrepreneurial Integration (EI)	0.31 (0.10)	[0.11, 0.51]	<0.05

Model Summary: $R^2 = 0.62$ | $F(3,52) = 21.4$, $p < 0.01$ | Adj. $R^2 = 0.59$
VIF Range = 1.8 – 3.2 | N = 56

Note: Points represent standardised coefficients (β); horizontal lines show 95% confidence intervals. *$p < 0.05$, **$p < 0.01$

Figure 3: Standard Regression Coefficient Predicting Sustainable Housing Outcomes

It visualises β values and significance levels and highlights the relative influence of variables



Note: Weighted Frequency Index (WFI). Error bars indicates 95% confidence intervals for proportions.

Figure 4: Weighted Frequency Index (WFI) of Entrepreneurial Outcomes

This compares entrepreneurial indicators

4.8 Synthesis of Results

The results demonstrate that fabric intelligence operates as an integrated performance system. Material innovation primarily drives carbon reduction, adaptive design enhances thermal performance, and entrepreneurial integration supports affordability and scalability. The convergence of descriptive and inferential findings—supported by strong effect sizes and statistically significant relationships—confirms that sustainable housing outcomes are best explained through coordinated system interactions rather than isolated interventions.

5.0 Discussion

5.1 Fabric Intelligence as a Socio-Technical Integration Mechanism

The findings substantiate fabric intelligence as a systems-based mechanism for sustainable housing delivery, where material innovation, adaptive design, and entrepreneurial integration operate as interdependent components rather than discrete variables. The regression model ($R^2 = 0.62$; $F = 21.4$, $p < 0.01$) indicates that a substantial proportion of housing performance outcomes is jointly explained by these interacting domains, reinforcing a systems integration logic. This aligns with socio-technical transitions theory, which posits that transformation in built environments emerges from the alignment of technologies, institutions, and socio-economic practices (Khan et al., 2022; Parracho et al., 2025).

Within this framework, fabric intelligence functions as a mediating construct that connects material systems with design processes and production networks. The implication is that sustainability gains are contingent on coordinated system performance rather than isolated technological improvements. This repositions architectural practice from object-based design to process-oriented coordination, in which architects act as integrators of material, environmental, and economic systems.

5.2 Material Innovation and Ecological Modernisation

Material innovation exhibits the strongest statistical influence on environmental performance ($\beta = –0.49$, $p < 0.01$), confirming its central role in reducing embodied carbon. The observed mean reduction of 33.8% situates textile-informed systems within the upper range of low-carbon construction strategies, consistent with prior evidence on material substitution and lifecycle optimisation (Zhong et al., 2021; Gursel et al., 2023; Kane et al., 2025).

From a theoretical standpoint, these results support ecological modernisation theory, which argues that environmental improvements can be achieved through technological innovation and resource efficiency rather than reduced development intensity (Ruíz & Mack-Vergara, 2023). Textile systems achieve such efficiencies through reduced material mass, structural optimisation, and multifunctional performance, thereby lowering lifecycle emissions without compromising functional outcomes.

However, the results also indicate that material innovation alone does not guarantee system-wide sustainability. Its effectiveness is contingent on integration with design strategies and delivery systems, suggesting that ecological modernisation must be operationalised through system coordination rather than technological substitution alone.

5.3 Adaptive Design and Climate-Responsive Performance

Adaptive design demonstrates a statistically significant contribution to housing performance ($\beta = -0.27$, $p < 0.05$), particularly in enhancing thermal comfort. The average temperature reduction of 3.1°C indicates a meaningful improvement in indoor environmental conditions, especially within tropical climates where passive cooling is critical.

This finding reinforces the role of textile-informed systems as climate-responsive design mechanisms, capable of translating material properties into environmental performance outcomes. The flexibility inherent in textile structures enables dynamic interaction with climatic variables such as solar radiation, airflow, and humidity, thereby supporting passive environmental control (Hassan et al., 2025; Wyller et al., 2020).

Theoretically, this aligns with adaptive systems thinking within architecture, where buildings are conceived as responsive entities rather than static forms. Textile logics—such as modularity, layering, and deployability—extend this responsiveness to spatial and structural configurations (Tamke et al., 2020; Shi et al., 2024). The implication is that sustainable housing requires not only efficient materials but also design intelligence capable of mediating environmental conditions in real time.

5.4 Entrepreneurial Integration and Socio-Economic Transformation

The positive coefficient for entrepreneurial integration ($\beta = 0.31$, $p < 0.05$) underscores the role of economic systems in shaping scalability and affordability. High WFI values for local production and employment confirm that textile-informed housing systems are strongly associated with distributed manufacturing and local value chains.

This supports sustainable entrepreneurship theory, which emphasises the role of innovation-driven enterprises in addressing environmental and social challenges while generating economic value (Harsanto et al., 2023; Khokhawala & Iyer, 2022). In this context, textile systems extend beyond material innovation to function as economic enablers, embedding housing production within localised systems of labour, skills, and enterprise.

In developing economies such as Nigeria, where informal construction and artisanal production dominate, this integration enhances economic resilience and inclusivity (Igwe et al., 2019; Ozigbo et al., 2025). However, persistent constraints—particularly limited access to finance, weak institutional support, and fragmented supply chains—highlight the need for enabling frameworks that formalise and scale these systems (Onwuakpa, 2023). Thus, entrepreneurial integration is not merely an outcome but a precondition for the scalability of sustainable housing.

5.5 Cultural Embeddedness and Indigenous Knowledge Systems

The integration of indigenous knowledge emerges as a critical dimension of fabric intelligence, reinforcing the cultural and social sustainability of housing systems. Textile practices in Nigeria are deeply embedded in artisanal traditions, community identities, and local production systems (Anyanwu et al., 2022; Hidayani, 2024). Their incorporation into architectural processes enhances contextual relevance and user acceptance.

This finding aligns with broader theories of cultural sustainability, which emphasise the role of local knowledge in shaping resilient and adaptive built environments (Brown & Vacca, 2022; McHattie & Ting, 2024). Textile systems serve as a bridge between traditional craftsmanship and modern construction technologies, enabling hybrid solutions that are both innovative and culturally grounded.

Moreover, the use of locally embedded systems enhances adaptability to environmental and socio-economic conditions, thereby improving resilience (Enwin & Ikiriko, 2024; Garba et al., 2024). Fabric intelligence can therefore be conceptualised as a culturally embedded innovation system, rather than a purely technological construct.

5.6 Structural Constraints and Implementation Dynamics

Despite demonstrated performance benefits, the adoption of textile-informed housing systems remains constrained by institutional, regulatory, and technical barriers. Existing regulatory frameworks often prioritise conventional materials and construction methods, limiting the integration of alternative systems (Alfahad et al., 2022). Additionally, skill gaps, lack of standardisation, and limited empirical validation of long-term performance create uncertainty for stakeholders.

The fragmentation of research across architecture, textiles, and entrepreneurship further compounds these challenges by limiting the development of integrated implementation strategies. The present findings address this limitation by demonstrating that interdisciplinary convergence is essential for scalability.

From a systems perspective, these constraints highlight the importance of governance and institutional alignment in enabling socio-technical transitions. Without supportive policies, financing mechanisms, and capacity development, the potential of fabric intelligence cannot be fully realised.

5.7 Integrated Implications for Theory, Practice, and Policy

The study advances theoretical understanding by embedding fabric intelligence within a multi-dimensional systems framework that integrates ecological modernisation, socio-technical transitions, and sustainable entrepreneurship. This synthesis provides a more comprehensive explanation of how sustainability outcomes emerge in housing delivery systems.

From a practical standpoint, the findings redefine the role of architects as multi-scalar coordinators, responsible for aligning material innovation, adaptive design, and economic systems. This expands architectural practice beyond design production to include system integration and process orchestration.

At the policy level, the results underscore the need for enabling environments that support innovation, local production, and entrepreneurship. Regulatory reform, financial incentives, and institutional coordination are critical for unlocking the potential of textile-informed housing systems.

5.8 Synthesis

Overall, the evidence advances a systems-based interpretation in which sustainable housing outcomes depend less on the isolated effectiveness of individual strategies and more on the architect’s capacity to coordinate material, design, and economic systems within a unified framework. Fabric intelligence, therefore, represents not only a technological innovation but a transformative paradigm for integrating environmental performance, design adaptability, and socio-economic inclusion in housing delivery.

6.0 Recommendations and Conclusion

6.1 Recommendations

The findings demonstrate that fabric intelligence can only translate into scalable housing outcomes when supported by coordinated policy, technical capacity, production systems, and institutional alignment. Accordingly, the following recommendations are proposed to operationalise the Architecture–Textile–Entrepreneurship framework.

Governments should transition from prescriptive building codes to performance-based regulatory frameworks that accommodate textile-informed and lightweight construction systems. This requires the formal recognition of alternative materials through standardisation, certification protocols, and testing guidelines. Approval processes should be streamlined through digitised permitting systems and one-stop regulatory platforms, with clearly defined performance benchmarks for structural safety, durability, and environmental performance. Establishing national standards for textile-based construction components will reduce uncertainty and enhance industry adoption.

The effective implementation of fabric-intelligent systems depends on the availability of skilled professionals across design, fabrication, and construction. Academic institutions should integrate textile-informed architectural design, digital fabrication, and modular construction into curricula, while professional bodies should promote continuous training for architects, engineers, and artisans. Cross-disciplinary collaboration between the architecture and textile departments should be institutionalised to foster innovation and technical competence.

To enhance affordability and economic inclusion, housing delivery systems should prioritise localised production networks. Governments and development partners should support the establishment of regional fabrication hubs that integrate textile production with the manufacturing of housing components. Financial incentives, including tax reliefs, grants, and access to microfinance, should be provided to small and medium-scale enterprises engaged in textile-based construction supply chains. This approach will reduce dependency on imported materials while strengthening local economies.

Digital technologies should be leveraged to improve efficiency, precision, and scalability. The adoption of parametric design tools, Building Information Modelling (BIM), and digital fabrication techniques can enhance material optimisation and reduce construction waste. Distributed manufacturing systems should be supported to enable decentralised production, particularly in regions with limited industrial infrastructure. Public–private partnerships can facilitate technology transfer and infrastructure investment.

Fabric intelligence must be embedded within robust entrepreneurial ecosystems to achieve scalability. Policy frameworks should support the integration of informal and artisanal enterprises into formal housing delivery systems through access to finance, market linkages, and capacity development. Programmes that promote skill development, enterprise incubation, and cooperative production models should be prioritised to enhance value chain efficiency and employment generation.

Housing solutions should incorporate indigenous knowledge and culturally embedded practices to enhance acceptance and sustainability. Textile traditions, including weaving and dyeing, should be adapted for architectural applications to ensure that innovation remains contextually relevant. Participatory design approaches should be encouraged to engage local communities in the co-creation of housing solutions, thereby improving adoption and long-term performance.

Effective implementation requires coordinated action across multiple stakeholders, including government agencies, private developers, textile producers, financial institutions, and community organisations. Integrated governance frameworks should be established to align policy, design, production, and financing mechanisms. Inter-agency collaboration platforms should be created to reduce fragmentation and ensure coherent housing delivery strategies.

To bridge the gap between research and practice, pilot housing projects should be developed to test textile-informed construction systems under real-world conditions. These projects should evaluate environmental performance, cost efficiency, and socio-economic impacts, generating empirical evidence to support policy adoption and industry scaling. Demonstration programmes will also enhance stakeholder confidence and facilitate knowledge transfer.

6.2 Conclusion

This study set out to examine how fabric intelligence—defined as the integration of textile-informed material systems, adaptive architectural design, and entrepreneurial value chains—can enhance sustainable housing delivery in developing contexts. Through a PRISMA-based systematic review of 56 peer-reviewed studies, the research provides robust empirical and analytical evidence that sustainable housing outcomes are best understood as the result of interdependent system interactions rather than isolated technical or design interventions.

The findings demonstrate that material innovation plays a dominant role in reducing embodied carbon and improving environmental performance, while adaptive design enhances thermal comfort, flexibility, and climate responsiveness. Entrepreneurial integration, in turn, strengthens affordability and scalability by embedding housing delivery within local production systems and value chains. The convergence of these dimensions confirms that fabric intelligence operates as a coordinated mechanism linking environmental efficiency, design adaptability, and socio-economic inclusion, thereby offering a viable pathway for addressing the complex challenges of housing delivery in rapidly urbanising regions.

Beyond performance outcomes, the study establishes that textile-informed systems provide a unique opportunity to bridge traditional knowledge and modern construction technologies. By incorporating indigenous materials, artisanal skills, and culturally embedded practices, fabric intelligence enhances contextual relevance, user acceptance, and long-term sustainability. At the same time, advances in digital fabrication and modular construction enable scalability and efficiency, reinforcing the potential for widespread adoption.

Despite these advantages, the study acknowledges that implementation remains constrained by regulatory rigidity, limited technical capacity, fragmented institutional frameworks, and weak integration between informal and formal production systems. Addressing these barriers requires coordinated interventions across policy, practice, and research domains, as highlighted in the recommendations.

6.3 Contribution to Knowledge

This study makes four key contributions:

Empirical Contribution: It consolidates quantitative and qualitative evidence from 56 peer-reviewed studies, providing statistically validated insights into the performance of textile-informed housing systems, including measurable reductions in carbon emissions, improvements in thermal performance, and gains in construction efficiency.

Theoretical Contribution: It advances the concept of fabric intelligence by extending it into a systems-based housing delivery framework that integrates socio-technical transitions, ecological modernisation, and sustainable entrepreneurship.

Methodological Contribution: It demonstrates the application of a PRISMA-based systematic review combined with quantitative meta-pattern analysis and inferential statistics, offering a replicable approach for interdisciplinary research in the built environment.

Practical Contribution: It proposes an Architecture–Textile–Entrepreneurship Framework that offers actionable guidance for architects, policymakers, and industry stakeholders to deliver low-carbon, culturally responsive, and economically inclusive housing systems.

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