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GREEN STRATEGY OF SHELL BRICK FOR SUSTAINABLE ARCHITECTURE

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ABSTRACT

The construction industry contributes significantly to global carbon emissions and environmental degradation, creating increasing demand for sustainable building materials. This research aims to formulate a green strategy for enhancing the value of shell brick as an environmentally friendly building material within the perspective of sustainable architecture and circular economy principles. The study uses a qualitative case study approach through SWOT analysis integrated with Olson's Green Strategy framework. Primary data were collected through observations, interviews, and documentation studies involving shell brick industries in Dumai City, Indonesia. The results identify seven strategic dimensions requiring development, namely raw material management, production techniques, processing technology, distribution systems, marketing strategies, institutional development, and architectural applications. The findings indicate that shell brick has strong potential as a sustainable architectural material due to its utilization of palm oil industrial waste through reuse, reduce, and recycle principles. The study also demonstrates that shell brick supports green building concepts through reduced embodied carbon potential, local resource utilization, and environmentally responsive architectural applications. This research contributes to the development of sustainable construction materials and green architecture practices in tropical regions.

KEYWORDS: shell brick, green architecture, sustainable materials, circular economy, palm oil waste

*Industri konstruksi menjadi salah satu penyumbang utama emisi karbon global dan degradasi lingkungan sehingga mendorong kebutuhan terhadap pengembangan material bangunan berkelanjutan. Penelitian ini bertujuan merumuskan strategi hijau (*green strategy*) untuk meningkatkan nilai shell brick sebagai material bangunan ramah lingkungan dalam perspektif arsitektur berkelanjutan dan ekonomi sirkular. Penelitian menggunakan pendekatan studi kasus kualitatif melalui analisis SWOT yang diintegrasikan dengan kerangka* Green Strategy *Olson. Data primer diperoleh melalui observasi lapangan, wawancara semi-terstruktur, dan dokumentasi pada industri shell brick di Kota Dumai, Indonesia. Hasil penelitian menunjukkan terdapat tujuh dimensi strategis yang memerlukan pengembangan, yaitu pengelolaan bahan baku, teknik produksi, teknologi pengolahan, sistem distribusi, strategi pemasaran, pengembangan kelembagaan, dan aplikasi arsitektural. Temuan penelitian memperlihatkan bahwa shell brick memiliki potensi kuat sebagai material arsitektur berkelanjutan karena memanfaatkan limbah industri kelapa sawit melalui prinsip* reuse, reduce, *dan* recycle. *Material ini juga mendukung konsep bangunan hijau melalui pengurangan potensi karbon terbangun (*embodied carbon*), pemanfaatan sumber daya lokal, dan penerapan desain arsitektur yang responsif terhadap lingkungan tropis. Penelitian ini berkontribusi terhadap pengembangan material konstruksi berkelanjutan dan praktik arsitektur hijau pada kawasan tropis.*

KATA KUNCI: *shell brick, arsitektur hijau, material berkelanjutan, ekonomi sirkular, limbah kelapa sawit*

INTRODUCTION

The construction industry remains one of the largest contributors to global carbon emissions and environmental degradation. The United Nations Environment Programme reported that buildings and construction activities contribute significantly to global energy-related carbon emissions due to material extraction, manufacturing processes, transportation, and operational energy consumption (UNEP, 2023). This condition encourages the development of sustainable building materials capable of reducing environmental impacts throughout the building lifecycle.

Indonesia is recognized as the world's largest producer of Crude Palm Oil (CPO), with plantation areas exceeding 16 million hectares and annual production surpassing 50 million metric tons. Palm oil processing industries generate substantial quantities of solid waste, including palm kernel shells, boiler ash, mesocarp fibers, and empty fruit bunches. Most of these waste materials remain underutilized despite possessing potential as alternative construction resources.

The conversion of industrial waste into sustainable building materials has become increasingly relevant within green architecture and circular economy discourse. Chen et al. (2024) explained that agricultural and industrial waste transformation into construction materials may reduce landfill pressure, minimize environmental pollution, and support sustainable material cycles in the built environment.

Shell brick is an alternative masonry material utilizing palm shell combustion residue combined with cement, sand, and water. The material is intended as a substitute for conventional fired clay bricks, which often generate environmental damage through soil excavation and high-temperature kiln burning processes. Hamada et al. (2020) emphasized that palm shell derivatives possess potential as lightweight construction aggregates due to their relatively low density and environmental advantages. Serri et al. (2015) further demonstrated that oil palm shell lightweight aggregate concrete exhibits favorable engineering performance, durability, and thermal properties, supporting its application within sustainable construction systems.

Within architectural practice, sustainable materials are increasingly evaluated not only from structural performance but also from environmental responsiveness, embodied energy reduction, thermal behavior, and compatibility with tropical passive design strategies. Sustainable tropical architecture encourages the use of local materials, low-carbon construction systems, and environmentally adaptive building envelopes (Prasetyo et al., 2023).

Despite possessing environmental advantages, shell brick industries continue to face various limitations including traditional production systems, weak institutional management, limited market penetration, and inadequate technological support. These conditions reduce the competitiveness of shell brick products within wider construction markets.

This study aims to formulate a green strategy for enhancing shell brick value through the integration of SWOT analysis and Olson’s Green Strategy framework while simultaneously examining the relevance of shell brick within sustainable tropical architecture.

Green Architecture and Sustainable Materials

Green architecture refers to environmentally responsive architectural approaches emphasizing energy efficiency, resource conservation, ecological integration, and sustainable building performance. Grierson and Moultrie (2011) explained that sustainable architectural design requires integration between material selection, environmental systems, and building performance strategies.

Contemporary green architecture increasingly prioritizes sustainable building materials possessing low embodied carbon, recycled content, local availability, and minimal environmental impacts. Rahman et al. (2021) stated that agricultural waste-based materials have gained significant attention due to their potential contribution toward environmentally sustainable construction systems. The utilization of industrial and agricultural waste within architecture also supports circular economy principles emphasizing material recirculation, waste minimization, and long-term environmental sustainability (Kirchherr et al., 2017).

Palm Oil Waste Utilization in Construction

Palm oil industrial waste has become an important subject within sustainable construction research. Palm shell waste and boiler ash possess potential applications as lightweight aggregates and masonry components. Hamada et al. (2020) reviewed the use of oil palm shell in cement concrete applications and identified promising mechanical and environmental properties. Kareem et al. (2022) further emphasized that palm shell utilization may contribute toward pollution-free construction and sustainable material innovation.

Recent studies by Olofinnade et al. (2025) demonstrated that palm shell materials can achieve satisfactory structural performance within ecofriendly paving systems. Shafigh et al. (2017) specifically investigated the thermal properties of oil palm shell lightweight aggregate concrete, revealing its potential for energy-efficient building envelopes in tropical climates. These findings indicate that shell-based materials possess significant opportunities for wider architectural and construction applications.

Green Strategy Framework

Olson (2008) introduced the Green Strategy framework as an enterprise-level sustainability strategy consisting of multiple dimensions including operational strategy, technological strategy, organizational development, and environmental leadership. The framework categorizes sustainability maturity into several stages consisting of aware, developing, practicing, optimizing, and leading. The framework is relevant for evaluating industrial readiness in adopting sustainable production systems and environmentally responsive business strategies.

METHODS

This study employed a qualitative case study approach to examine shell brick development within the context of sustainable architecture and green industry strategies. The research was conducted in Dumai City, Riau Province, Indonesia, due to its strategic role as a downstream palm oil industrial zone under the MP3EI development program. Dumai City was selected because of the availability of palm oil industrial waste and the existence of shell brick production industries operating for decades.

Primary data were collected through direct observations, semi-structured interviews, and documentation studies. The field observation process focused on:

- Shell brick production workflows,
- Raw material management,
- Labor involvement,
- Production capacity,
- Equipment utilization,
- Distribution systems,
- And marketing conditions.

The primary database generated from field observations is presented in Table 1.

Table 1. Primary observation database of shell brick industry

Observation aspect	Findings
Number of business units	More than 10 SMEs
Daily production capacity	200–250 units/day
Main raw materials	Palm shell ash, sand, cement, water
Production method	Manual pressing and sun drying
Workforce characteristics	Small-scale local labor
Production duration	Approximately 10 minutes/unit
Marketing coverage	Local construction market

(Source: Author's field observations, 2026)

Semi-structured interviews were conducted with:

- 10 shell brick business owners,
- 15 production workers,
- and 5 distributors.

The interviews explored themes including production management, raw material availability, technological limitations, market conditions, institutional development, and sustainable construction opportunities. To improve research validity, this study applied data triangulation through the integration of observations, interviews, and documentation analysis. The collected empirical findings were subsequently categorized into SWOT indicators consisting of strengths, weaknesses, opportunities, and threats. The SWOT findings were then integrated into Olson's Green Strategy framework to formulate strategic recommendations for shell brick development.

RESULTS AND DISCUSSION

Shell Brick Production Characteristics

Field observations identified that shell brick industries in Dumai City generally operate as small-scale industries utilizing semi-traditional production systems. Most production activities remain dependent on manual labor with limited technological support. Production sites commonly involve 3–7 workers handling material preparation, molding, pressing, drying, and distribution activities. The shell brick production process consists of:

1. Palm oil shell waste collection;
2. Shell combustion process;
3. Boiler ash collection;
4. Material mixing;
5. Molding and pressing;
6. Sun drying process;
7. Finished shell brick products.

Figure 1. Shell Brick Production Workflow
(Source: Authors' illustration based on field observations, 2026)

The production observations revealed several operational limitations including inconsistent material composition, limited pressing equipment, low production efficiency, and absence of standardized operating procedures. Despite these limitations, shell brick industries demonstrate strong environmental potential because approximately 50% of the primary material composition originates from palm oil industrial waste.

SWOT Analysis

The SWOT matrix was formulated based on the synthesis of field observations, interviews, and secondary literature analysis. Internal factors consisting of strengths and weaknesses were derived from industrial conditions including production systems, labor conditions, technological utilization, and organizational management.

Table 2. Internal Factors of the strengths and weaknesses

Strengths	Weaknesses
50% raw materials derived from industrial waste	Non-integrated production systems
Established supplier relationships	Lack of government collaboration
Strategic industrial location	Traditional production processes
Long production experience	Absence of SOP standardization
Self-owned production facilities	Simplistic financial management
Workforce training experience	Weak organizational structure
Competitive pricing	Unclear long-term sustainability vision
Government SME registration	Limited handling equipment

External factors consisting of opportunities and threats were identified through market trends, environmental policies, sustainable construction demand, and regional industrial development conditions.

Table 3. External Factors ofthe opportunities and threats

Opportunities	Threats
Indonesia as global CPO producer	Negative perceptions toward waste-based materials
Large palm oil plantation areas	Exclusion from standard building price analysis
MP3EI downstream industrial support	Export-oriented waste contracts
Green building market growth	Limited certification support
Unique architectural appearance	Market acceptance uncertainty

Figure 2. SWOT Matrix of Shell Brick Development

(Source: Authors' analysis based on field interviews and industrial observations, 2026

Green Strategy Maturity Analysis

The SWOT findings were subsequently integrated into Olson's Green Strategy framework to determine shell brick industry maturity levels.

The findings indicate that shell brick industries remain within early sustainability maturity stages due to limited technological and institutional capabilities. However, significant opportunities exist for transitioning toward optimized and leading sustainability practices through improved production systems, certification development, and green building integration.

Table 4. shell brick industry maturity levels

Strategic Factor	Current Level	Target Level
Raw materials	Aware	Leading
Processing techniques	Aware	Practicing
Processing technology	Aware	Optimizing
Distribution	Aware	Leading
Marketing	Aware	Optimizing
Institutional development	Aware	Practicing
Architectural application	Aware	Optimizing

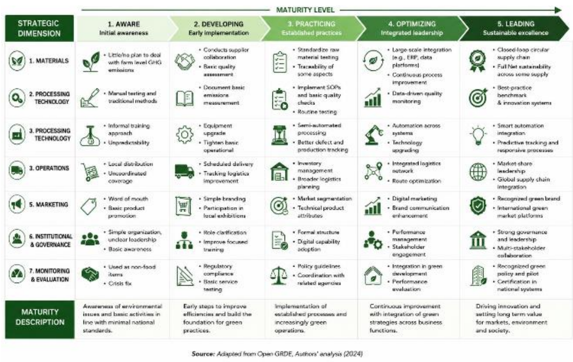

Figure 3. Green Strategy Maturity Framework for Shell Brick Industry

(Source: Adapted from Olson, 2008)

Green Architecture Perspective

Figure 4. Circular Economy Concept of Shell Brick Utilization

(Source: Adapted from Ellen MacArthur Foundation, 2019).

From the perspective of sustainable architecture, shell brick demonstrates several environmental and architectural advantages. The material supports reuse, reduce, and recycle principles through the transformation of palm oil industrial waste into construction products.

The use of shell brick may reduce dependence on conventional fired clay bricks, which often contribute to environmental degradation through excessive soil extraction and energy-intensive firing processes.

Shell brick also demonstrates relevance within tropical sustainable architecture due to its lightweight characteristics and exposed natural texture. Architecturally, shell bricks may support:

- Exposed facade concepts,
- Passive tropical design,
- Reduced finishing applications,
- And environmentally responsive building envelopes

From a thermal perspective, lightweight shell brick composition potentially contributes toward lower heat absorption compared to dense conventional masonry materials. Shafigh et al. (2017) confirmed that oil palm shell lightweight concrete exhibits lower thermal conductivity compared to conventional concrete, making it suitable for passive cooling strategies in warm-humid tropical climates. Sulaiman et al. (2024) further demonstrated that palm kernel shell ash-based geopolymer concrete provides excellent thermal properties and fire resistance, reinforcing the potential of shell-based materials within sustainable tropical building systems. The material therefore demonstrates potential compatibility with passive cooling strategies in warm-humid tropical climates.

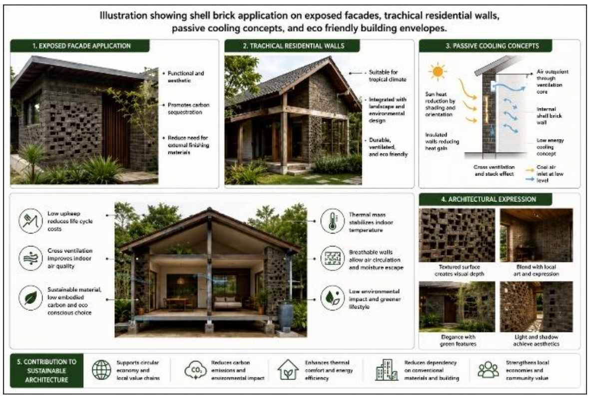

Figure 5. Architectural Application of Shell Brick in Tropical Sustainable Design
(Source: Author's conceptual illustration based on sustainable tropical architecture principles, 2026)

Sustainable Building Integration Framework

The integration of shell bricks within sustainable building systems supports low-carbon architectural development through:

- Local material utilization,
- Reduced embodied energy,
- Waste valorization,
- And environmentally responsive construction approaches.

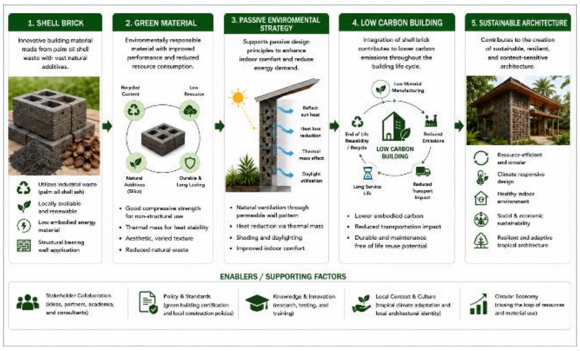

Figure 6. Sustainable Building Integration Framework Using Shell Brick
(Source: Adapted from green architecture and sustainable building frameworks, 2026)

Sulaiman et al. (2024) emphasized that the utilization of palm kernel shell ash within geopolymer concrete represents an advancement toward sustainable construction materials, offering both environmental benefits through waste valorization and enhanced thermal performance for building applications. The utilization of shell bricks reflects the transition from linear construction systems toward circular architectural practices emphasizing resource efficiency and environmental sustainability.

CONCLUSIONS

This research demonstrates that shell brick possesses strong potential as an environmentally friendly construction material within sustainable tropical architecture. The integration of SWOT analysis and Olson's Green Strategy framework successfully identified seven strategic dimensions requiring development, namely raw material management, production systems, processing technology, distribution, marketing, institutional development, and architectural applications.

The findings indicate that shell brick contributes toward circular economy implementation through the transformation of palm oil industrial waste into alternative building materials. Architecturally, shell bricks support sustainable building concepts through local material utilization, reduced environmental impacts, and compatibility with passive tropical design strategies. This study also demonstrates that shell brick utilization extends beyond material substitution and contributes toward low-carbon architectural development and environmentally responsive construction systems

Based on the SWOT analysis and Green Strategy maturity assessment, several recommendations are proposed.

For industry stakeholders

Standardize production SOPs and quality control systems;

- Upgrade pressing and molding technology;
- Develop technical product specifications and certifications;
- Expand collaboration with green building suppliers and architects.

For government institutions

- Provide technical assistance and certification support;
- Encourage domestic utilization of palm oil industrial waste;
- Integrate shell brick into sustainable construction programs.

For future research

- Conduct lifecycle assessment (LCA) studies;
- Investigate thermal and acoustic performance;
- Explore broader architectural applications within tropical buildings.

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