

Cross-Laminated Timber as an Alternative Housing System for Tropical Peatlands: Evidence from Sarawak, Malaysia

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ABSTRACT

The convergence of affordable housing demand, flood exposure and problematic ground conditions presents a distinctive challenge for housing development on tropical peatlands. This study explores the feasibility of Cross-Laminated Timber (CLT) as an alternative construction system for affordable and flood-resilient housing in Sarawak, Malaysia. An exploratory qualitative case-study design was adopted, using purposive sampling to obtain perspectives from stakeholders with relevant expertise in construction, structural engineering, architecture, timber and engineered wood products, housing development, academia and regulatory practice. Data were collected through semi-structured interviews and analysed using thematic analysis. The findings indicate that the feasibility of CLT is multidimensional and cannot be determined solely by its structural or environmental attributes. Its relatively low structural mass offers a potentially important advantage on highly compressible peat by reducing superstructure loading and, consequently, foundation demand, while prefabrication may improve construction efficiency and support whole-system cost optimisation. However, these advantages remain conditional upon effective flood-adaptive design, moisture management, biological and termite protection, connection durability, fire and adhesive performance, manufacturing consistency and regulatory acceptance. The analysis further highlights the distinction between the availability of local timber resources and readiness to manufacture structurally certified CLT products. The study concludes that CLT represents a promising but conditional pathway for affordable housing on tropical peatlands rather than an immediately deployable substitute for conventional construction.

Keywords: Cross-Laminated Timber; affordable housing; flood resilience; peatlands; Sarawak.

INTRODUCTION

The construction sector is under increasing pressure to reconcile the growing demand for affordable housing with the need to reduce environmental impacts and strengthen resilience to climate-related hazards (Adeyemi et al., 2024; McKee et al., 2026). Housing provision is particularly challenging in communities where socioeconomic vulnerability intersects with difficult environmental and geotechnical conditions. Low-income households often require housing that is not only affordable at the point of construction but also durable, maintainable, adaptable and capable of responding to local environmental risks. These requirements have intensified interest in alternative construction systems that can reduce structural weight, accelerate construction,

minimise material consumption and support more sustainable forms of housing development (Shufrin et al., 2023). Within this context, engineered timber systems, particularly Cross-Laminated Timber (CLT), have emerged as a potential alternative to conventional concrete and masonry construction (De Araujo et al., 2023).

The challenge is especially relevant in Malaysia, where affordable housing remains an important component of national and state socioeconomic development (Shuid, 2016; Tobi et al., 2020). Evidence from Sarawak demonstrates the financial vulnerability of lower-income households, particularly among B40 groups, whose expenditure priorities tend to concentrate on essential needs during periods of economic stress (Mohamad et al., 2024a). More broadly, interventions targeting economically vulnerable populations should be considered within a multidimensional development perspective, encompassing poverty alleviation, income improvement and wider socioeconomic well-being (Esa et al., 2025). Accordingly, affordable housing should be understood not merely as a construction-cost issue, but as part of a broader strategy for strengthening household welfare and socioeconomic resilience.

Housing development also has broader economic significance, as residential construction generates linkages with employment, manufacturing, real estate and wider economic activity (Mohamad et al., 2024b). Various housing programmes have been implemented to improve access to adequate housing among lower-income communities (Ariaee & Takaloo, 2024; Willis & Mohsin, 2025). Nevertheless, housing vulnerability cannot necessarily be addressed through housing provision or relocation alone. Evidence from low-income resettlement communities in Sibul, Sarawak, indicates that some households continue to experience deteriorating housing conditions, limited financial capacity for maintenance and overcrowding (Rahman et al., 2022). Household expansion may also result in informal or poorly planned extensions to existing dwellings, potentially creating additional structural and safety concerns. Consequently, affordable housing requires consideration not only of initial construction costs but also of long-term maintainability, adaptability and suitability to the environmental conditions in which the housing is constructed. This broader perspective is particularly relevant in Sarawak, where empirical evidence indicates that housing preferences are influenced not only by affordability but also by location, environmental quality and housing characteristics (Mohamad et al., 2025).

These concerns become more complex in parts of Sarawak characterised by extensive tropical peat deposits (Rahman et al., 2023). Peat soils present significant challenges for conventional construction because of their high compressibility and relatively low bearing capacity (Jamatia et al., 2025). In the context examined in Sibul, settlements constructed over deep and soft peat soils are exposed to ground subsidence and differential settlement, which may contribute to structural deterioration and cracking in rigid concrete and masonry structures. The problem is compounded by hydrological conditions, including waterlogged ground, inadequate drainage and recurrent flooding (Kaiser & Akter, 2025). The interaction between weak ground conditions and flood exposure therefore creates a distinctive housing challenge in which affordability, structural loading, durability and resilience must be considered simultaneously.

Conventional concrete and masonry construction may impose substantial structural loads on weak peat foundations, potentially increasing foundation and piling requirements (Kaladi et al., 2023). This has important implications for affordable housing because expenditure on ground improvement and foundation systems may represent a substantial component of development costs. A lightweight construction system could consequently offer an alternative strategy for reducing the structural demand imposed on peat soils (Ogut et al., 2022; Jorat et al., 2024). Within this context, CLT deserves further investigation because of its comparatively high strength-to-weight characteristics and its potential application as structural wall, floor and roof elements. The source material underpinning this study indicates that CLT has substantially lower density than concrete and argues that reducing superstructure dead load may reduce foundation demands in peatland construction.

CLT is an engineered wood product manufactured by bonding multiple layers of timber in alternating perpendicular directions (Kurzinski et al., 2022). This cross-laminated configuration improves dimensional stability and enables the resulting panels to resist loads in more than one direction (Li et al., 2024). CLT panels can consequently function as structural walls, floors and roofs, allowing significant portions of a building to be manufactured as prefabricated components (De Araujo et al., 2023). The prefabrication characteristics of CLT may also be advantageous for affordable housing because components can be manufactured off-site and rapidly assembled on-site. Such a construction approach has the potential to reduce site activities, shorten construction

periods and minimise dependence on labour-intensive wet trades. These characteristics may be particularly relevant in areas where difficult ground conditions and recurrent flooding complicate conventional site-based construction.

Beyond structural weight and construction efficiency, CLT has attracted attention because of its environmental characteristics. Unlike highly carbon-intensive construction materials, timber originates from a renewable biological resource when sourced through appropriately managed forestry systems. Carbon absorbed during tree growth can remain stored within timber products throughout their service life, providing CLT with potential advantages in reducing the embodied carbon associated with building construction (Dodoo et al., 2022). The underlying concept for this study further identifies potential reductions in construction waste and embodied carbon through the substitution of conventional structural materials with mass-timber systems. These characteristics create a potential connection between affordable housing provision, climate-responsive construction and broader sustainable development objectives.

For Sarawak, the feasibility of CLT may also be associated with opportunities to develop locally sourced engineered timber products. Conventional CLT systems developed in North America and Europe commonly rely on established softwood species (Kurzynski et al., 2022). However, transferring these systems directly into a tropical context may not necessarily be economically or technically appropriate. One potential pathway involves investigating locally available timber species capable of supporting a regional mass-timber supply chain (Mensah et al., 2025). In this respect, *Gmelina arborea* has been identified as a fast-growing tropical species with potential relevance to CLT production in Sarawak (Asyiqin & Ong, 2025). Nevertheless, variability in timber characteristics and vulnerability of particular portions of the wood to biological deterioration indicate that appropriate grading, processing and durability considerations would be required before widespread structural application.

Despite these potential advantages, adopting CLT within a tropical and flood-prone environment presents important uncertainties. Much of the technical rationale for CLT depends upon effective moisture management. Prolonged exposure to liquid water and elevated moisture conditions may increase the risk of mould, dimensional changes and fungal deterioration (Wu & Wong, 2022; Singh, 2024). These concerns become particularly significant in Sarawak because of its humid tropical climate, high rainfall and flood exposure. Termite activity represents an additional challenge, particularly where moisture management or protective detailing is inadequate. Fire performance and the behaviour of structural adhesive systems under elevated temperatures must likewise be considered when developing locally manufactured CLT systems (Wiesner et al., 2022; Yasir et al., 2025). Therefore, the technical advantages associated with lightweight timber construction cannot be considered independently of moisture protection, biological durability, fire safety, material treatment and appropriate architectural detailing.

The feasibility of CLT for affordable housing is also broader than technical performance alone. Successful adoption of an alternative construction system requires an enabling ecosystem involving material availability, manufacturing capacity, construction expertise, regulatory acceptance, cost competitiveness, maintenance requirements and stakeholder confidence (Wielopolski & Bulthuis, 2023). This is particularly important for affordable housing, where a technologically sophisticated solution may have limited practical value if it results in excessive initial costs, specialised maintenance requirements or dependence on materials and expertise unavailable within the local construction industry. Similarly, the adoption of CLT may be constrained where building regulations, approval procedures, professional familiarity or local supply chains have not developed sufficiently to accommodate mass-timber construction (Ilgin & Karjalainen, 2023a). The existing concept therefore identifies local procurement, regulatory pathways and community skills development as important considerations for translating CLT from an experimental construction system into a practical housing solution.

Although the technical and environmental potential of CLT provides a rationale for considering the material as an alternative construction system, its applicability to affordable housing constructed on tropical peatlands cannot be inferred solely from its performance in other geographical settings. The combination of highly compressible peat soils, recurrent flooding, high humidity, biological deterioration risks, affordability constraints and the developing nature of the local mass-timber ecosystem creates a context that requires specific investigation. More importantly, technical suitability represents only one dimension of feasibility. The

perceptions, experiences and concerns of stakeholders responsible for designing, constructing, regulating and delivering housing can substantially influence whether an innovative construction technology can realistically progress towards implementation.

Therefore, this study aims to explore the feasibility of adopting Cross-Laminated Timber for affordable and flood-resilient housing on tropical peatlands in Sarawak, Malaysia. Specifically, the study seeks (1) to explore stakeholders' perceptions of the potential benefits of CLT for affordable housing on tropical peatlands; (2) to identify the technical, economic and institutional barriers affecting CLT adoption in Sarawak; and (3) to propose strategies for facilitating the adoption of CLT for affordable and flood-resilient housing.

Through semi-structured interviews and thematic analysis, the study provides empirical insights into the conditions under which CLT could become a feasible alternative housing system within Sarawak's distinctive socioeconomic and environmental context. In doing so, the study contributes to the emerging discussion on sustainable mass-timber construction by extending the debate beyond conventional applications towards the intersection of affordable housing, flood resilience and construction on tropical peatlands.

METHODOLOGY

This study employed an exploratory qualitative case-study design to investigate the feasibility of Cross-Laminated Timber (CLT) as an alternative construction system for affordable and flood-resilient housing on tropical peatlands in Sarawak, Malaysia. A qualitative approach was considered appropriate because the application of CLT within the Sarawak context remains relatively underexplored, particularly in relation to affordable housing, peatland construction and flood-prone environments. Rather than experimentally evaluating the structural performance of CLT, the study focused on understanding stakeholder perceptions regarding its potential benefits, technical limitations, economic implications, institutional barriers and conditions required for implementation.

The case-study approach enabled these issues to be examined within the specific environmental, construction and socioeconomic context of Sarawak. The research design was aligned with the three research objectives: (1) to explore stakeholders' perceptions of the potential benefits of CLT for affordable housing on tropical peatlands; (2) to identify the technical, economic and institutional barriers affecting CLT adoption in Sarawak; and (3) to propose strategies that could facilitate the adoption of CLT for affordable and flood-resilient housing.

Study Context

The study was conducted in Sarawak, Malaysia, with particular attention to housing development in areas characterised by tropical peat soils and exposure to flooding. This context was selected because peat soils are generally associated with high compressibility and low bearing capacity, creating significant challenges for conventional housing construction. The study also considered the broader requirements of affordable housing, including construction cost, maintainability, adaptability and long-term performance.

CLT was examined as a potential alternative construction system because of its relatively lightweight structural characteristics, prefabrication potential and capacity to function as integrated wall, floor and roof components. At the same time, the Sarawak context presents specific challenges for engineered timber construction, including high humidity, heavy rainfall, moisture exposure, biological deterioration, termite risks, fire performance and the availability of appropriate manufacturing and regulatory systems. These conditions provided the contextual basis for examining stakeholder perceptions of CLT feasibility.

Participant Selection and Sampling

Purposive sampling was employed to select participants with professional knowledge and experience relevant to the research problem (Campbell et al., 2020; Dahal et al., 2024). This approach was appropriate because the study required information-rich participants capable of providing informed perspectives on construction, structural engineering, architecture, timber and engineered wood products, housing development, research and regulatory practice. A total of 10 stakeholders were selected for the study. Participants represented relevant

professional backgrounds associated with the technical, economic and institutional dimensions of CLT adoption. Selection was based on participants' professional expertise and their ability to contribute directly to the research objectives rather than on statistical representativeness.

Eligible participants were required to possess relevant professional experience or expertise in at least one of the following areas: construction and housing development; structural or civil engineering; architecture; timber or engineered wood products; building materials; construction on peat soils or flood-prone environments; academic research related to construction or sustainable materials; or housing planning, regulation and policy. The use of participants from different professional backgrounds enabled the study to capture the multidimensional nature of CLT feasibility rather than assessing the proposed construction system exclusively from an engineering perspective.

Data Collection

Primary data were collected through semi-structured interviews with the 10 selected stakeholders. Semi-structured interviews were used because they provided a consistent framework for addressing the research objectives while allowing participants to elaborate on issues arising from their professional knowledge and experience. Each interview lasted approximately 30–45 minutes and was conducted either face-to-face or through an online meeting platform, depending on participant availability. With participants' consent, interviews were audio-recorded to facilitate accurate transcription and subsequent analysis. The interview protocol was structured around three main areas corresponding to the research objectives. The first explored the perceived benefits and suitability of CLT for affordable housing constructed on tropical peatlands. The second examined technical, economic and institutional barriers that could influence CLT adoption. The third focused on strategies and enabling conditions considered necessary for the future implementation of CLT in Sarawak.

The main interview questions were:

1. What are the major challenges associated with constructing affordable housing on peat soils in Sarawak?
2. What is your understanding or experience of engineered timber products, particularly CLT?
3. What potential advantages could CLT offer compared with conventional concrete or masonry housing?
4. How suitable do you consider lightweight CLT construction for flood-prone peatland areas?
5. What technical challenges could affect the use of CLT under Sarawak's tropical conditions?
6. What economic, cost or supply-chain factors could influence CLT adoption?
7. What institutional, regulatory or industry-related barriers could affect its implementation?
8. What measures would be required to make CLT a feasible option for affordable and flood-resilient housing in Sarawak?

Follow-up questions were used where necessary to obtain clarification and further explanation. Particular attention was given to structural weight, foundation requirements, construction efficiency, affordability, moisture management, termite protection, fire safety, maintenance, local timber availability, professional capability, regulatory approval and supply-chain readiness.

Alignment between Research Objectives and Data Collection

Table 1 shows how the interview protocol was directly aligned with the three research objectives to ensure methodological coherence. Questions 1–4 addressed the first research objective by exploring perceived suitability, benefits and opportunities associated with CLT. Questions 5–7 addressed the second research

objective by examining technical, economic, supply-chain, regulatory and institutional barriers. Question 8 and the associated follow-up questions addressed the third research objective by identifying potential strategies, interventions and enabling conditions for CLT adoption.

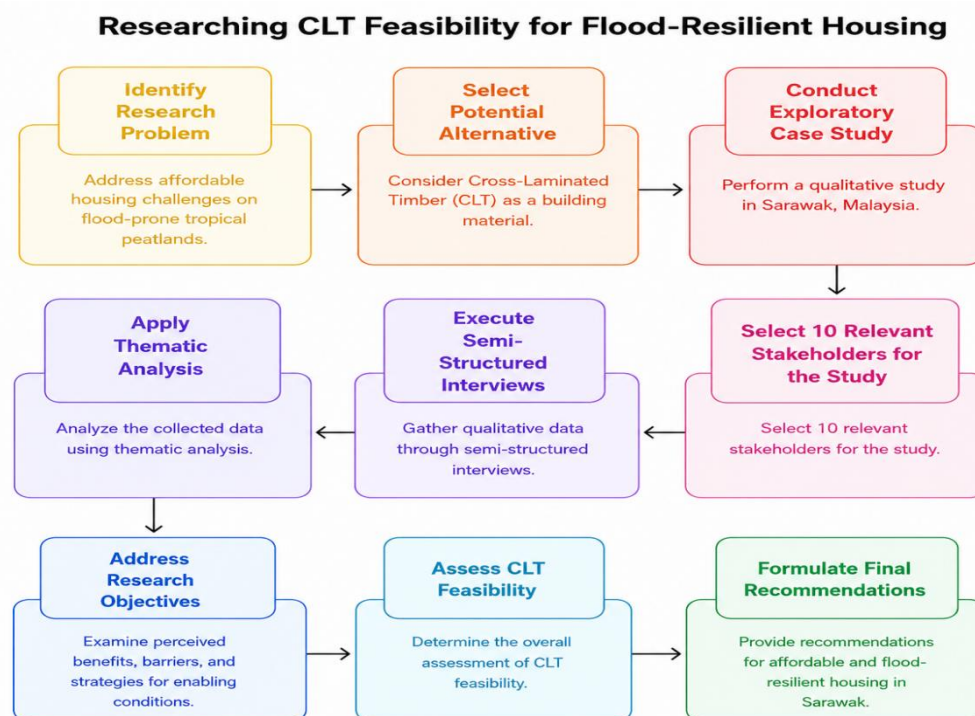
Table 1. Interview Protocol

Research Objective	Focus of Investigation	Interview Questions	Analytical Dimension
RO1: Explore stakeholders' perceptions of the potential benefits of CLT for affordable housing on tropical peatlands	Suitability, benefits and opportunities	Q1–Q4	Perceived feasibility and benefits
RO2: Identify technical, economic and institutional barriers affecting CLT adoption in Sarawak	Technical limitations, cost, supply chain, regulation and industry readiness	Q5–Q7	Adoption barriers
RO3: Propose strategies for facilitating CLT adoption for affordable and flood-resilient housing	Required interventions, policies and implementation conditions	Q8 and follow-up questions	Adoption strategies and enabling conditions

This alignment established a systematic analytical sequence from perceived benefits and suitability, through barriers and constraints, to implementation strategies. Collectively, these dimensions provided the basis for evaluating stakeholder-perceived feasibility of CLT within the Sarawak affordable-housing context.

Methodological Framework

The methodological framework of the study can therefore be represented as follows:



This methodological structure establishes a direct connection between the research problem, research objectives, data collection and analytical process. Rather than attempting to demonstrate the structural performance of CLT experimentally, the study provides an empirical stakeholder-based assessment of whether CLT is perceived as a feasible construction alternative and identifies the conditions that would be required for its future adoption in affordable and flood-resilient housing on tropical peatlands.

RESULTS AND DISCUSSION

The thematic analysis of the stakeholder interviews revealed that the feasibility of Cross-Laminated Timber (CLT) for affordable and flood-resilient housing on tropical peatlands is multidimensional. Stakeholders did not perceive CLT as an immediate replacement for conventional reinforced concrete or masonry construction. Rather, its feasibility was understood to depend on the interaction between structural efficiency, geotechnical conditions, construction cost, environmental exposure, durability, manufacturing capability and institutional readiness.

Seven interconnected themes emerged from the analysis: (1) structural lightweighting as a response to peatland constraints; (2) prefabrication and whole-system affordability; (3) flood resilience through elevated construction; (4) moisture management and biological durability; (5) structural connections and fire performance; (6) localisation of timber resources and manufacturing; and (7) professional and institutional readiness. These themes correspond closely with the technical, economic and institutional dimensions investigated through the interview protocol.

A key pattern emerging across the themes was that stakeholders generally recognised the potential advantages of CLT but viewed these advantages as conditional. Lightweight construction, for example, could potentially reduce the structural demand imposed on peat foundations, but it would not eliminate the need for appropriate foundation engineering (Jorat et al., 2024). Similarly, prefabrication could reduce construction time and site labour, but these benefits could be offset by manufacturing, transportation, protection and certification costs. The findings therefore indicate that CLT feasibility should be evaluated at the level of the complete housing system rather than solely according to the properties of the timber panels.

Structural Lightweighting as a Response to Peatland Constraints

The first major theme concerned the relationship between structural weight and the challenging geotechnical characteristics of tropical peatlands. Stakeholders recognised that housing construction on peat soils is affected by low bearing capacity, high compressibility, settlement and ground instability. Within this context, the comparatively low structural mass of CLT was perceived as one of its most relevant potential advantages.

The findings suggest that reducing superstructure weight could decrease the permanent load transferred to piles, pile caps, stilts and other foundation components. This is particularly relevant because the existing study context identifies peatland construction as requiring careful consideration of foundation demand. CLT has been considered within the project partly because of its substantially lower density compared with conventional concrete construction (Li & Tsavdaridis, 2023).

Nevertheless, the analysis also indicates that the lightweight characteristics of CLT should not be interpreted as a solution to peat behaviour itself. Peat remains a highly compressible material whose response depends on factors such as peat depth, decomposition, groundwater conditions, applied loading and foundation configuration (Debnath et al., 2025). Consequently, reducing superstructure weight may alleviate part of the structural demand but cannot remove the requirement for appropriate geotechnical investigation and engineered foundations.

This distinction is important for establishing a realistic interpretation of CLT feasibility. The potential value of CLT lies in reducing one component of the geotechnical challenge rather than eliminating it. In practical terms, lower structural loads may create opportunities to optimise pile dimensions, foundation quantities or other supporting elements. However, the extent of these potential savings cannot be established through stakeholder perceptions alone and would require subsequent geotechnical and structural testing (Abushama et al., 2024).

The finding therefore extends the conventional environmental rationale for mass timber. In the Sarawak context, lightweight construction has potential value not only because timber may substitute carbon-intensive materials but because structural mass itself is an important design consideration when building over problematic peat soils. CLT can therefore be conceptualised as a potentially site-responsive structural strategy, subject to engineering validation.

Prefabrication and Whole-System Affordability

The second theme concerned the potential economic advantages associated with CLT prefabrication. Stakeholders viewed off-site manufacturing and rapid on-site assembly as potentially beneficial for housing construction in environments where rainfall, site accessibility and difficult ground conditions can affect construction productivity. CLT allows wall, floor and roof panels to be manufactured within a controlled environment before transportation to the construction site. Digital design coordination, precision cutting and preformed openings can reduce the amount of fabrication required on site. For repetitive affordable housing projects, standardised components could also provide opportunities for greater production efficiency. However, the findings indicate that the affordability of CLT should not be assessed solely by comparing the unit cost of CLT panels with concrete, masonry or other conventional materials. Instead, affordability needs to be evaluated from a whole-system perspective. This interpretation is particularly important because CLT may simultaneously introduce additional costs and generate savings in other areas.

Potential additional costs include panel manufacturing, structural adhesives, timber treatment, specialised connectors, digital fabrication, transportation, certification and quality assurance. Conversely, possible savings may arise from reduced foundation requirements, shorter construction periods, lower site-labour requirements and reduced dependence on wet trades. Selected exposed CLT surfaces may also reduce the requirement for secondary finishes such as plasterboard, suspended ceilings or painting, depending on architectural and fire-performance requirements. These system-level trade-offs are already evident in the existing analysis.

The findings consequently suggest an affordability paradox. CLT may have a comparatively high initial material or manufacturing cost while potentially reducing expenditure elsewhere within the building system (Ilgin et al., 2023b). Therefore, categorising CLT simply as either expensive or affordable would be premature. Scale is also important. Prefabricated construction becomes economically more attractive when standardisation and production volume enable fixed manufacturing costs to be distributed across multiple units. For affordable housing, CLT may therefore be better suited to standardised or repetitive development than isolated individual construction. A comprehensive techno-economic assessment comparing functionally equivalent CLT and conventional housing systems would be required to determine whether these theoretical advantages result in measurable whole-system savings.

Flood Resilience Through Elevated Construction

The third theme concerned the suitability of CLT within flood-prone environments. The findings indicate that CLT should not itself be described as inherently flood-resistant. Timber-based materials remain vulnerable to prolonged moisture exposure, particularly when water enters joints or enclosed assemblies and cannot dry effectively. Instead, stakeholders' assessment supports understanding flood resilience as a characteristic of the complete housing system. In this configuration, the principal CLT superstructure would be elevated above the expected flood level and supported by an appropriate pile or stilt foundation system. This arrangement separates the moisture-sensitive timber superstructure from direct contact with wet ground and anticipated floodwater (Opabola et al., 2026). The findings similarly position elevation and exposure avoidance as central to the proposed resilience strategy.

This approach shifts the design philosophy from attempting to make CLT intrinsically resistant to flooding towards reducing its exposure to floodwater. The effectiveness of such a strategy would depend on appropriate floor elevation, drainage, protection of interfaces, roof and façade detailing, and the capacity of components to dry following incidental moisture exposure. However, elevation alone is insufficient. External stairs, decks, service penetrations, wall-floor junctions and timber-to-concrete interfaces may provide pathways for moisture ingress. Flood-resilient CLT housing therefore requires continuity of protection across the entire building envelope. The findings consequently indicate that flood resilience should be understood as an integrated outcome of site planning, foundation design, elevation, structural detailing, drainage, moisture management and maintenance. This systems perspective provides a more technically defensible basis for considering CLT within flood-prone tropical peatlands (Wulandari et al., 2024).

Moisture Management and Biological Durability

Moisture management emerged as one of the most critical technical conditions affecting the feasibility of CLT in Sarawak. The tropical environment combines high humidity, heavy rainfall and potential flood exposure, creating conditions that differ substantially from many established CLT markets. The findings indicate that the principal concern is not simply whether timber becomes temporarily wet but whether moisture remains trapped within the panel or building assembly. Prolonged moisture exposure may contribute to mould growth, staining, dimensional changes and fungal deterioration (Kuka et al., 2022). Particular attention is therefore required at panel edges, exposed end grain, wall-floor connections, openings, roof interfaces and service penetrations.

Construction-stage moisture exposure is equally important. Panels manufactured under controlled factory conditions may subsequently be exposed to rainfall during transportation, storage and erection. If wet panels are enclosed before adequate drying occurs, moisture may become trapped within concealed assemblies (Nakajima, 2026). The findings therefore indicate the need for a formal moisture-management protocol covering the entire construction process. This would include protective packaging, delivery sequencing, off-ground storage, temporary weather protection, rapid enclosure, moisture inspection and verification before concealed assemblies are completed. Moisture should consequently be treated as a measurable quality-control parameter rather than solely as a post-construction maintenance issue.

Closely related to moisture management is biological durability. Termite activity represents an important concern for timber structures within tropical environments. The findings suggest that termite resistance should be approached through multiple protective barriers rather than reliance on a single treatment. Such an approach could combine elevation from soil, physical barriers, appropriate preservative treatment, moisture control, inspection access and scheduled maintenance. However, preservative treatment creates an additional technical consideration because treatment systems must remain compatible with the structural adhesives used in CLT production. The findings further identify the interaction between timber characteristics, preservatives, adhesives, moisture and manufacturing conditions as a material-system optimisation problem. Therefore, tropical durability cannot be considered an isolated material property (Castañeda Valdés et al., 2024). It represents an integrated performance requirement involving material selection, manufacturing, architectural detailing, construction quality and long-term maintenance.

Structural Connections and Fire Performance

The fifth theme concerned structural connections and fire performance. The findings indicate that satisfactory panel properties alone would be insufficient to establish the feasibility of CLT housing. The performance of the complete structural system depends heavily on the interfaces connecting walls, floors, roofs and foundations. This consideration is particularly important for an elevated housing configuration. The interface between the CLT superstructure and the pile or stilt foundation must transfer gravity forces while providing adequate resistance to lateral actions, uplift and movements associated with the building and supporting ground. Differential movement could place additional demands on these interfaces.

Environmental exposure further increases the importance of connection design. Metallic connectors may be vulnerable to corrosion under humid or intermittently wet conditions when unsuitable materials or protection systems are used. Connection durability must therefore be considered together with moisture management. The analysis identifies panel joints, timber-to-concrete interfaces, adhesive bond lines and penetrations as critical points at which different materials and environmental conditions converge.

Fire performance represents another critical condition for technical and regulatory acceptance. Mass timber can develop a protective char layer during fire exposure, but this characteristic does not mean that all CLT products provide equivalent fire resistance. Fire performance depends on the complete product configuration. Of particular concern is adhesive delamination. At elevated temperatures, deterioration of the adhesive bond may allow charred laminations to separate, potentially exposing previously protected timber. This issue is especially important for locally manufactured CLT because performance established for an internationally certified CLT product cannot automatically be transferred to a locally produced panel using a different timber species or adhesive.

Accordingly, any locally developed CLT system would require specific validation of charring behaviour, residual structural capacity, adhesive integrity, connection performance and potential delamination. The findings therefore position fire validation as a prerequisite for regulatory acceptance rather than an issue that can be assumed from the general properties of mass timber.

Localisation of Timber Resources and Manufacturing

The sixth theme concerned the possibility of developing a locally based CLT supply chain. Local production was viewed as strategically relevant because it could potentially reduce dependence on imported CLT products while creating higher-value applications for regional timber resources. Within the existing study, *Gmelina arborea* has been identified as a potentially relevant fast-growing tropical species (Kabir et al., 2025).

However, the findings emphasise an important distinction between timber availability and structural product readiness. The availability of timber does not automatically mean that the material is suitable for immediate conversion into structural CLT. Structural products require predictable mechanical properties, controlled moisture content, dimensional stability and reliable adhesive bonding. Variability that may be acceptable for conventional timber applications may become problematic when the material is used within primary load-bearing panels.

Localisation would therefore require systematic characterisation of *Gmelina arborea*, including mechanical properties, density, moisture behaviour, dimensional stability, defects, bonding response and biological durability (Yau et al., 2024). Appropriate grading procedures would also be necessary to ensure consistency. Manufacturing capacity represents an equally important requirement. Structural CLT production involves controlled drying, grading, surface preparation, adhesive application, pressing, curing, machining and quality assurance. Weakness at any stage could compromise panel performance.

Consequently, localisation should not be interpreted simply as substituting imported softwood with a locally available species. Rather, it requires the development of a complete engineered-timber manufacturing ecosystem incorporating raw-material management, processing technology, quality assurance, testing, certification and professional expertise. If successfully developed, such an ecosystem could potentially generate broader economic benefits by strengthening local timber value chains and supporting higher-value manufacturing. However, these potential benefits remain conditional on successful technical validation.

Professional Capability and Institutional Readiness

The final major theme concerned the professional and institutional environment required to support CLT adoption. The findings indicate that technical feasibility alone would not be sufficient to enable widespread implementation. The Malaysian construction industry has extensive experience with reinforced concrete and masonry construction, supported by established standards, procurement systems, professional competencies and regulatory procedures (Dehdasht et al., 2022; Yusof et al., 2025). CLT would introduce comparatively unfamiliar requirements involving timber engineering, connection detailing, moisture management, digital fabrication, erection planning and fire engineering.

The findings therefore reveal an implementation capability gap. Limited experience among designers, contractors, manufacturers and approval authorities could increase uncertainty and perceived project risk. Early CLT projects may consequently face additional consultation, testing, design coordination and regulatory requirements. Rather than treating this as a reason to reject CLT, the findings indicate the need for progressive capability development. Demonstration projects, professional training, technical guidelines and university-industry collaboration could provide opportunities to develop local knowledge and reduce uncertainty.

Regulatory development should nevertheless proceed alongside technical validation. Authorities require defensible evidence regarding material properties, structural performance, adhesives, connections, moisture durability, termite resistance and fire performance before establishing or adapting approval pathways. Institutional readiness therefore represents a critical final stage in the transition from a technically promising concept to an implementable construction system.

From Potential to Feasibility and Readiness

Synthesising the seven themes reveals an important distinction between potential, feasibility and readiness. CLT demonstrates potential because several characteristics correspond with specific challenges associated with affordable housing on tropical peatlands. Its comparatively low structural mass may reduce foundation demand, prefabrication may improve construction efficiency, elevated construction may support flood-responsive design, and local timber resources may provide opportunities for regional production.

However, potential does not automatically establish feasibility. Feasibility depends on whether critical technical and economic conditions can be satisfactorily addressed. These include moisture management, biological durability, termite protection, connection performance, fire safety, adhesive performance, manufacturing consistency and whole-system affordability. Similarly, feasibility does not necessarily establish readiness. A technically and economically feasible CLT housing system may still be unsuitable for immediate widespread implementation where manufacturing capability, professional expertise, certification procedures, regulatory pathways and maintenance capacity remain insufficiently developed. This distinction represents an important outcome of the analysis. CLT adoption should therefore be conceptualised as a staged progression:

Potential → Demonstrated Feasibility → Institutional and Market Readiness → Implementation

Such a progression avoids prematurely categorising CLT as either suitable or unsuitable for Sarawak. Instead, it identifies the evidence and capabilities required to move from conceptual potential towards practical implementation.

A Context-Specific Feasibility Framework for Tropical Peatlands

Taken together, the seven empirical themes can be synthesised into five higher-order feasibility dimensions: geotechnical compatibility, technical performance, tropical durability, techno-economic viability and institutional readiness. This resolves the distinction between the seven detailed themes and the five dimensions used in the final conceptual framework. Geotechnical compatibility concerns whether the reduction in structural mass associated with CLT produces meaningful advantages for foundation design on highly compressible peat.

Technical performance concerns whether CLT panels, structural connections, foundations and complete assemblies can satisfy structural and fire-performance requirements. Tropical durability encompasses moisture management, biological deterioration, termite protection, material compatibility and long-term serviceability. Techno-economic viability concerns whether potential benefits from prefabrication, shorter construction periods and reduced foundation demand can offset the additional costs associated with manufacturing, protection, specialised components, testing and certification (Nguyen et al., 2026). Institutional readiness concerns whether adequate manufacturing capability, standards, professional expertise, regulatory mechanisms and industry confidence exist to support implementation. These five dimensions are consistent with the framework already developed in the manuscript.

The findings consequently position CLT as a promising but conditional construction pathway for affordable and flood-resilient housing on Sarawak's tropical peatlands. The lightweight characteristics of CLT provide a compelling context-specific rationale for further investigation, particularly because of the geotechnical limitations associated with peat. Nevertheless, the transition from conceptual potential to practical implementation requires systematic local validation.

A staged development pathway is therefore recommended, beginning with local timber characterisation and material testing, followed by panel, adhesive and connection validation. Subsequent stages should involve prototype construction, moisture and termite monitoring, fire-performance evaluation and field testing under representative tropical peatland conditions. A comprehensive techno-economic assessment should then compare the complete CLT housing system with an equivalent conventional construction system.

The principal finding is therefore not that CLT should immediately replace reinforced concrete or masonry housing in Sarawak. Rather, the study demonstrates that CLT possesses characteristics that could address several

constraints associated with affordable housing on tropical peatlands, while simultaneously identifying the technical, environmental, economic and institutional conditions that must be satisfied before implementation can be justified. This provides a more cautious and empirically appropriate basis for advancing CLT research and development within tropical, flood-prone and geotechnically challenging environments.

CONCLUSION AND LIMITATION

This study explored the feasibility of Cross-Laminated Timber (CLT) for affordable and flood-resilient housing on tropical peatlands in Sarawak, Malaysia. The findings position CLT as a promising but conditional construction pathway, particularly because its relatively low structural mass may reduce foundation demand on highly compressible peat, while prefabrication offers potential efficiencies in construction time, labour and whole-system cost. However, these advantages cannot be considered independently of the environmental and technical conditions that characterise tropical peatland development.

The study demonstrates that CLT feasibility is shaped by five interdependent dimensions: geotechnical compatibility, technical performance, tropical durability, techno-economic viability and institutional readiness. Of particular importance is the distinction between *potential*, *feasibility* and *readiness*. Although CLT possesses characteristics that respond to peatland construction constraints, practical feasibility depends on effective moisture management, biological protection, reliable connections, fire and adhesive performance, manufacturing consistency and economic competitiveness. Similarly, flood resilience should be understood as a system-level outcome achieved through appropriate elevation, foundation design, drainage and moisture-responsive detailing rather than as an inherent property of CLT.

These conclusions should be interpreted within the exploratory nature of the study. As the evidence is derived from stakeholder perceptions, the study establishes the conditions under which CLT may be considered feasible rather than experimentally demonstrating its engineering performance. Furthermore, its geographical focus on Sarawak means that the findings are context-dependent and should not be generalised uncritically to other tropical environments.

Future research should therefore translate the identified feasibility conditions into empirical validation through local timber characterisation, structural and connection testing, moisture and termite durability assessment, fire-performance evaluation and full-scale prototype monitoring under representative peatland conditions. Comparative techno-economic analysis should subsequently determine whether the anticipated reductions in foundation and construction requirements translate into measurable whole-system savings. Such evidence would provide the necessary bridge between stakeholder-perceived feasibility and technically validated implementation, enabling a more rigorous assessment of CLT as a sustainable and resilient affordable-housing system for tropical peatlands.

REFERENCES

1. Abushama, K., Hawkins, W., Pelecanos, L., & Ibell, T. (2024). Embodied carbon optimisation of concrete pile foundations and comparison of the performance of different pile geometries. *Engineering Structures*, 310, 118109.
2. Adeyemi, A. B., Ohakawa, T. C., Okwandu, A. C., Iwuanyanwu, O., & Ifechukwu, G. O. (2024). Affordable housing and resilient design: Preparing low-income housing for climate change impacts. *Journal of Sustainable Architecture*, 12(2), 45-60.
3. Ariaee, A. M., & Takaloo, S. (2024). Impact of affordable housing programs on social equity and economic development. *International Journal of Management and Accounting*, 6(5), 108-117.
4. Asyiqin, A. B. N., & Ong, K. H. (2025). Adapting forest plantations to climate change: strategies, challenges, and opportunities in Malaysia. *New Forests*, 56(3), 35.
5. Campbell, S., Greenwood, M., Prior, S., Shearer, T., Walkem, K., Young, S., ... & Walker, K. (2020). Purposeful sampling: complex or simple? Research case examples. *Journal of research in Nursing*, 25(8), 652-661.

6. Castañeda Valdés, A., Corvo Pérez, F., Pech Pech, I., Marrero Águila, R., & Bastidas-Arteaga, E. (2024). Durability requirements for reinforced concrete structures placed in a hostile tropical coastal environment. *Buildings*, 14(8), 2494.
7. Dahal, N., Neupane, B. P., Pant, B. P., Dhakal, R. K., Giri, D. R., Ghimire, P. R., & Bhandari, L. P. (2024). Participant selection procedures in qualitative research: Experiences and some points for consideration. *Frontiers in Research Metrics and Analytics*, 9, 1512747.
8. De Araujo, V., Aguiar, F., Jardim, P., Mascarenhas, F., Marini, L., Aquino, V., ... & Christoforo, A. (2023). Is cross-laminated timber (CLT) a wood panel, a building, or a construction system? A systematic review on its functions, characteristics, performances, and applications. *Forests*, 14(2), 264.
9. Debnath, R., Dey, A. K., Paul, A., & Kundu, S. K. (2025). Critical appraisal of geo-engineering properties of tropical peat soils. *Sādhana*, 50(3), 200.
10. Dehdasht, G., Ferwati, M. S., Abidin, N. Z., & Oyedeji, M. O. (2022). Trends of construction industry in Malaysia and its emerging challenges. *Journal of Financial Management of Property and Construction*, 27(2), 161-178.
11. Dodoo, A., Nguyen, T., Dorn, M., Olsson, A., & Bader, T. K. (2022). Exploring the synergy between structural engineering design solutions and life cycle carbon footprint of cross-laminated timber in multi-storey buildings. *Wood Material Science & Engineering*, 17(1), 30-42.
12. Esa, M. S. M., Wahid, H., Yaacob, S. E., & Mohamad, A. H. H. (2025). Asnaf development outcome: A systematic literature review and logic model development. *SAGE Open*, 15(3), 1–20.
13. Ilgin, H. E., & Karjalainen, M. (2023a). Insights from Finnish experts on the construction practices and future prospects of Cross-Laminated timber (CLT). *Forests*, 15(1), 31.
14. Ilgin, H. E., Karjalainen, M., & Mikkola, P. (2023b). Views of Cross-Laminated timber (CLT) manufacturer representatives around the world on CLT practices and its future outlook. *Buildings*, 13(12), 2912.
15. Jamatia, D. K., Dey, A. K., & Debnath, R. (2025). Experimental study on the bearing capacity behaviour of branched piling for stabilisation of constructions on peat: A model investigation. *Mires and Peat*, 32, 30.
16. Jorat, M. E., Minto, A., Tierney, I., & Gilmour, D. (2024). Future carbon-neutral societies: minimising construction impact on groundwater-dependent wetlands and peatlands. *Sustainability*, 16(17), 7713.
17. Kabir, C. R., Islam, M., Hassan, M. B., & Rahman, M. (2025). Impact of local climate and large-scale climate drivers on the growth of *Gmelina arborea* Roxb. in a South Asian moist tropical forest. *Trees*, 39(2), 41.
18. Kaiser, Z. A., & Akter, F. (2025). From risk to resilience and sustainability: Addressing urban flash floods and waterlogging. *Risk Sciences*, 1, 100011.
19. Kaladi, F., Wang, F., & Kherazi, F. Z. (2023). Structural Stability: A Comprehensive Review of Pile Foundations in Construction. *Journal of Asian Development Studies*, 12(4), 412-425.
20. Kuka, E., Cirule, D., Andersone, I., Andersons, B., & Fridrihsone, V. (2022). Conditions influencing mould growth for effective prevention of wood deterioration indoors. *Applied Sciences*, 12(3), 975.
21. Kurzinski, S., Crovella, P., & Kremer, P. (2022). Overview of cross-laminated timber (CLT) and timber structure standards across the world. *Mass Timber Construction Journal*, 5(1), 1-13.
22. Li, H., Wei, Y., Lin, Y., Chen, S., & Chen, J. (2024). Out-of-plane characteristics of cross-laminated bamboo and timber beams under variable span three-point loading. *Construction and Building Materials*, 411, 134647.
23. Li, Z., & Tsavdaridis, K. D. (2023). Design for seismic resilient cross laminated timber (clt) structures: A review of research, novel connections, challenges and opportunities. *Buildings*, 13(2), 505.
24. McKee, M., Howden-Chapman, P., Braithwaite, I., & Bentley, R. (2026). Health-promoting housing policy in a changing climate: integrating affordability, security, and resilience. *Health promotion international*, 41(1), daaf238.
25. Mensah, P., Pimenta, A. S., de Melo, R. R., Amponsah, J., Tuo, G., Chakurah, I., ... & de Medeiros, P. L. (2025). The global supply chain of wood products: A literature review. *Forests*, 16(7), 1036.
26. Mohamad, A. H. H., Ab-Rahim, R., Kushairi, A. R. E., & Esa, M. S. M. (2024b). Housing market: A bibliometric analysis from 2020 to 2024. *International Journal of Academic Research in Business and Social Sciences*, 14(8), 274–295.

27. Mohamad, A. H. H., Ab-Rahim, R., Zainuddin, M. R. K. V., & Kushairi, A. R. E. (2024a). Spending behaviour toward the financial aid during COVID-19 in Sarawak. *International Journal of Academic Research in Accounting, Finance and Management Sciences*, 14(1), 154–172.
28. Mohamad, A. H. H., Kushairi, A. R. E., & Ho, J. C. B. (2025). Socioeconomic and locational determinants of house buying behaviour in Bintulu: A micro-level urban housing analysis. *International Journal of Research and Innovation in Social Science*, 9(8), 886–895.
29. Nakajima, M. (2026). Moisture Damage in Hot-Humid Buildings: Drying Deficit, Envelope Moisture Response, Mold-Risk Assessment, and Building Adaptation. *Buildings*, 16(14), 2801.
30. Nguyen, N., Javan, K., Jordan, A., Akbarnezhad, A., & Banihashemi, S. (2026). Techno-economic analysis of 3D printed modular housing: Productivity, cost, and environmental assessment. *Journal of Cleaner Production*, 539, 147461.
31. Ogut, O., Tzortzi, N. J., & Bertolin, C. (2022). Vertical green structures to establish sustainable built environment: A systematic market review. *Sustainability*, 14(19), 12349.
32. Opabola, E. A., Baiguera, M., Raby, A., Rossetto, T., Pomonis, A., Meilianda, E., ... & Marafini, F. (2026). Diagnosing Long-Term Divergence in Build Back Better Outcomes in Low-and Lower-Middle Income Communities. *International Journal of Disaster Risk Reduction*, 106190.
33. Rahman, H. F. A., Gapor, S. A., Echoh, D. U., & Moriat, R. (2022). The effects of poverty to housing condition: case study of Kampung Sentosa, Sibul, Sarawak. *Borneo Journal of Social Sciences and Humanities*, 4(1).
34. Rahman, N. A., Jol, C. J., Linus, A. A., Ming, C. K., Arif, P., Baharuddin, N., ... & Hamid, D. F. A. A. A. (2023). Treatment of tropical peat water in Sarawak peatlands nature reserve by utilising a batch electrocoagulation system. *Sustainable Chemistry for the Environment*, 4, 100043.
35. Shufrin, I., Pasternak, E., & Dyskin, A. (2023). Environmentally friendly smart construction—Review of recent developments and opportunities. *Applied Sciences*, 13(23), 12891.
36. Shuid, S. (2016). The housing provision system in Malaysia. *Habitat International*, 54, 210-223.
37. Singh, J. (2024). Water damage and mould growth in buildings: Causes, detection, identification, remediation and health implications. *Journal of Building Survey, Appraisal & Valuation*, 12(4), 321-332.
38. Tobi, S. U. M., Jasimin, T. H., & Rani, W. N. M. W. M. (2020). Overview of affordable housing from supply and demand context in Malaysia. In *IOP Conference Series: Earth and Environmental Science* (Vol. 409, No. 1, p. 012010). IOP Publishing.
39. Wielopolski, M., & Bulthuis, W. (2023). The better building initiative—a collaborative ecosystem involving all stakeholders as catalyst to accelerate the adoption of circular economy innovations in the construction sector. *Circular Economy and Sustainability*, 3(2), 719-733.
40. Wiesner, F., Hadden, R., Deeny, S., & Bisby, L. (2022). Structural fire engineering considerations for cross-laminated timber walls. *Construction and building materials*, 323, 126605.
41. Willis, C. M. A., & Mohsin, A. B. (2025). Affordable housing schemes in Malaysia: A review of systematic gaps. *International Journal of Real Estate Studies*, 19(2), 12-22.
42. Wu, H., & Wong, J. W. C. (2022). Mechanisms of indoor mold survival under moisture dynamics, a special water treatment approach within the indoor context. *Chemosphere*, 302, 134748.
43. Wulandari, R., Iswara, A. P., Qadafi, M., Prayogo, W., Astuti, R. D. P., Utami, R. R., ... & Andhikaputra, G. (2024). Water pollution and sanitation in Indonesia: a review on water quality, health and environmental impacts, management, and future challenges. *Environmental Science and Pollution Research*, 31(58), 65967-65992.
44. Yasir, M., Ruane, K., O’Ceallaigh, C., & Jaksic, V. (2025). Fire Performance of Cross-Laminated Timber: A Review of Standards, Experimental Testing, and Numerical Modelling Approaches. *Fire*, 8(10), 406.
45. Yau, Y., Ocholi, A., Kaura, J. M., Lawan, A., & Sulaiman, T. A. (2024). Experimental Evaluation of the Physical and Sorption Properties of Gmelina Arborea Timber for Development of Wood-based Materials. *Covenant Journal of Engineering Technology*.
46. Yusof, A. F. M., Yusnar, C., Illahi, Y. R., Maharjan, R., & Widyasamratri, H. (2025). Green Construction in Malaysia: Integrating Regulation, Sustainability, and Innovation for a Resilient Future. *Civil and Sustainable Urban Engineering*, 5(1), 53-68.