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Perspective of Construction Building Professionals on Low-Carbon Materials in Malaysia

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Abstract: Low-carbon (LC) materials and alternative technology must overcome various institutional policy and market constraints to gain greater acceptance in the construction sector. The primary impediments that must be addressed to build a viable and sustainable local construction sector are awareness and knowledge. To analyse the perspective on LC materials in the northern states of Malaysia, 93 companies were surveyed via their construction building professionals (CBPs) on awareness, usage frequency, user experience, drivers for material selection and barriers to LC material adoption in projects. To establish an understanding of CBPs and LC materials, survey data were analysed using semi-structured qualitative-quantitative approaches and the Statistical Package for the Social Sciences (SPSS), influenced by basic theory. 79.57% valid responses indicate that most participants had a low degree of awareness, with 95% confidence that there is no difference in the score levels of the overall viewpoints between architects, civil engineers and structural engineers. While unfired bricks (16.2%) are commonly and widely employed in construction projects, structural insulated panels (40.9%) are the most favourable LC materials for future projects. Client requirements, regulatory requirements and expectations of a shorter completion time are the most important factors driving CBPs to select LC materials, accounting for 44.6%, 37.8% and 37.8%, respectively. According to the CBPs, the main constraint factor to market acceptability is the "Lack of sustainable material information" (44.9%). The proposed recommendations include "Training on designing a building with LC material", "Clear regulation on limiting carbon emission in a project" and "Increase demonstration of projects and case studies" at a rate ranging from 36.5% to 43.2% to improve client and CBPs acceptance of LC materials for a more sustainable building sector.

Keywords: Construction building professionals, Low carbon material, Perspective, Construction industry, Sustainable

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INTRODUCTION

As construction companies, governments, authorities and societies have become increasingly concerned with the degradation of natural resources and environmental threats, low-carbon (LC) construction has become a far-reaching issue (Hulail, Ayob and Omar, 2016; Esmaeilifar et al., 2018; Ayob et al., 2021). The strong need for building and infrastructure expansion, particularly in developing countries, directs material extraction and emission demands and noticeably undermines climate targets (Giesekam, Barrett and Taylor, 2018). According to the Roadmap for Buildings and Construction in Asia 2020 to 2050, promoting LC materials and material efficiency in high-density development, as well as enhancing energy efficiency in manufacturing, would reduce the carbon emissions (CE) of materials over the entire life cycle (IEA [International Energy Agency], 2020).

To limit environmental and social consequences, governments around the world have adopted a number of regulations and guidelines (Mata et al., 2021). There has been numerous studies made towards various institution and manufacturers alike on identifying carbon dioxide (CO_2) content of construction materials (Yusof, Awang and Iranmanesh, 2017; Rasmussen et al., 2018; Fenner et al., 2018) and as a result, appropriate steps toward regulatory guidelines have been established in several countries. For instance, under the Climate Change Act, the United Kingdom (UK) government established a statutory goal for reducing greenhouse gas (GHG) emissions in 2008. A series of five-year carbon budgets, which are currently enshrined in law until 2032, is crucial for this transitional progress toward the 2050 target (Giesekam, Barrett and Taylor, 2018). The committee on climate change is responsible for monitoring the five-year carbon budgets, in which the government adopted an act of parliament to reduce 80% of GHG emissions in 1990 to 160 $MtCO_2$ equivalents (eq.) each year until 2050. Whereas in Australia, the national Climate Change Authority, a signatory to the Paris Agreement (PA), aspires to reach net-zero emissions by 2050 to stay within the advised carbon budget of 1% of global emissions. The building industry may grant 28% to Australia's 2030 emission reduction target if it achieves zero CO_2 emissions by that year, a reduction of up to AUD20 billion (Yu et al., 2017).

To bring the average global surface temperature rise to below 2°C, there is an increasing need to solve energy and emission issues related to building construction. Current energy frameworks have not yet properly understood how comprehensive the PA's implications are for the energy quarter (Gielen et al., 2019). It is crucial to switch from fossil fuels to LC formulations and guidelines since the CE of construction items such as concrete, steel and aluminium account for 9% of yearly GHG emissions (Giesekam, Barrett and Taylor, 2015). In 2050, according to the steadily increasing trend in global population, there will be 9 billion populations on the planet (Güereca, Jato-Espino and Lizasoain-Arteaga, 2019), and more than 230 billion square meters of new buildings are anticipated to be constructed. For instance, by 2035, India's floor space is expected to double. A more despairing fact is that two-thirds of those summations will happen rapidly in the Asian and African regions that are not currently subject to mandatory building energy rules. However, new construction is often unavoidable in these places; in such cases, a good focus on CE mitigation is required. The general trend across the globe indicates that the GHG emissions brought on by construction activities are primarily attributable to embedded emissions rather than operational emissions (Giesekam, Barrett and Taylor, 2018). Embodied emissions are those associated with the original production of a structure. Generally, this energy includes emissions of raw materials acquisition and transportation, processing and manufacturing of construction materials, transportation of materials to site, and energy consumed on-site in assembly. Using energy-efficient retrofits, operational CE can be reduced over time; however, when using renewable energy, embodied carbon occurs immediately. Between now and 2050, CE is predicted to account for almost half of all new construction emissions, so it is prudent to decarbonise construction materials and achieve zero emissions.

Despite current progress in understanding and awareness, CE remains a niche subject in Malaysia's sector. CE estimation and mitigation are likewise not routinised across all industries, groups and institutions. Indeed, the key motivator for our study was the poor existing perception of embodied carbon and CE, which varies widely between professions, organisations and individuals within those organisations. The significance of CE estimates and material selection is still frequently underestimated, and it is a major issue in disseminating knowledge in this highly fragmented sector. Furthermore, some segments of the industry remain sceptical of alternate LC materials. Advocates for LC construction are not taken seriously across the country and this issue remains a significant impediment to overcoming these entrenched attitudes. The routes to eliminating CE are time-consuming, complex, risk-averse and supplier-driven, requiring a variety of professions. Many of these players interact with one another at various stages of a single project (Ayob et al., 2018), but they have fundamentally distinct viewpoints and material interests. The core challenge is integrating LC construction into the building sector mainstream. This includes portraying it as consistent with existing goals and visible campaigns (for example, resource efficiency and circular economy techniques), as well as incorporating it with a broader range of material.

In the early 2000s, construction building professionals (CBPs) in advanced countries like the UK were aware of numerous alternative materials, like rammed earth and cross-laminated timber. Nonetheless, the use of these alternative and nonconventional materials remained minimal and unconsidered. These CBPs emphasised fundamental restrictions such as high prices, lack of skill and technical knowledge and insufficient client awareness (Watson et al., 2012). Giesekam, Barrett and Taylor (2015) proposed remarkable constraints of high price, inefficient provision of responsibility, industry value, unavailability of product and insufficiency of building-level carbon and benchmarks in a qualitative study of assessing the cultural and perceptual constraints within design teams. According to a recent study by Maqbool and Amaechi (2021), sustainable construction designs in the UK are the primary driver of sustainable construction exercise. However, excessive price weighting is still observed as the most severe constraint of the overall sustainable exercise. Wong et al. (2022) concluded that most Malaysian respondents understand climate sciences, with 86% of researchers and technologists from national oil and gas companies such as PETRONAS aware that the country is now taking steps to promote a cleaner, healthier and greener society, as well as adopting the PA's sustainable development goals (SDGs). Meanwhile, according to Yang and Yue (2021), China strongly advocates for green and sustainable development. However, in the current prefabrication building design and energy-saving technologies, for example, the notion still fails to reach the national CE requirement. Similarly, in Malaysia, the most recent study by Chan, Masrom and Yasin (2022), emphasised the importance of raising awareness on this topic because LC materials are not commonly used in this country. The adoption of LC materials is restricted by a lack of demonstration projects, regulations, high costs, a scarcity of qualified labour, a lack of design knowledge and information about life cycle assessment.

Appropriate building material selection is increasingly important for CBPs, such as architects and civil and structural (C&S) engineers (Balasbaneh, Marsono and Gohari, 2019). Architects and structural engineers are the major technical specialists involved in building project design and material selection. Structural engineers supervise the static execution of structures, whereas architects analyse the visual, aesthetic and functional standards regularly. Other stakeholders moderate the influence of these CBPs on material desire, but knowledge of perception and influence among these actors is lacking, which motivates this current study. The need to improve professional information exchange is important because progress can only be made if all project actors are committed to and understand the underlying concept and practice. Furthermore, extensive support is required from Malaysian professional institutions such as the Malaysian Institute of Architects, the Association of Consultant Engineers Malaysia and the Institution of Engineers Malaysia (IEM) in encouraging communication, knowledge, awareness and data sharing on sustainable buildings, including the reduction of CE emissions.

Previous research has focused on the limitations of specific forms of green building and sustainable building. Some of these studies inclusively explained broad definitions of sustainability, incorporating economic and social factors (Hwang and Tan, 2012; Güereca, Jato-Espino and Lizasoain-Arteaga, 2019; Ohueri, Enegbuma and Habil, 2019; Willar et al., 2021), while others focused specifically on the environmental aspects of sustainability (Yusof, Awang and Iranmanesh, 2017), but excluded the embodied carbon of building materials. Furthermore, few studies have focused specifically on constraints to alternative material preference as a means of mitigating embedded CE. Thus, the primary objective of this research is to identify the practical, technical, economic and cultural barriers that prevent CBPs from selecting a variety of materials known to have lower embodied carbon. After highlighting the limiting issues, the following section presents potential strategies for overcoming the constraints and improving LC construction. This study seeks CBPs who will serve as a representative sample of Malaysia's northern region in this industry. The perspectives and experiences of those who have used LC materials will shape the industry's future approach to CE reduction. Understanding their awareness, motives, experience and perceived limits is also useful in expanding regulatory strategies and guidelines for the broader sustainable industry.

LITERATURE REVIEW

Net-Zero Emission in the Building Sector

Malaysia's energy sectors include fuel combustion activities in the energy industry, transportation, manufacturing and construction. In 2016, these sectors produced around 334,635 Gg $CO_{2eq.}$ of GHG emissions. The net emissions after accounting for total removal were 75,488 Gg $CO_{2eq.}$, the highest since 1994 (Wong et al., 2022). Building construction consumes a significant amount of energy, accounting for 36% of total energy consumption and 39% of energy and process-related CO_2 emissions in 2018. Building sectors in the ASEAN countries, China and India particularly accounted for 24% of energy-associated CO_2.

Executing zero emissions from the existing building stock needs to leverage building intervention points. This action can speed up the rate of energy upgrades, such as by expanding energy efficiency, abolishing on-site fossil fuels and producing 100% renewable energy (Architect 2030, 2022). According to the United Nations Environment Program's (UNEP) emissions gap report (IEA, 2020), global emissions must be reduced by over 50% by 2030 and moved towards carbon neutrality by 2050. To achieve this aim, decarbonising buildings for the whole life cycle would need modification within the building sector. 11% of global emissions are the result of manufacturing building materials. Visioning net-zero operational CE buildings calls for clear and determined policy instructions to drive a range of measures, including passive building design, material effectiveness, LC materials, the capability of building envelope measures and other distinct efficient appliances.

The Perspective of Low-Carbon Materials for Sustainable Construction

The SDG adopted by the United Nations General Assembly (UNGA) in 2015 established a powerful structure for international cooperation in achieving a successful and sustainable future globe. This involves additional efforts such as adequacy, circular and sharing economy, CE mitigation and life cycle consideration (Hertwich et al., 2019; the more efficient use of these materials presents a significant opportunity for the mitigation of greenhouse gas (GHG Mata et al., 2021). As the largest global consumer of materials, buildings are the sector with the highest single use. Adaptation of low fossil fuels in the construction industry to LC solutions is important to decrease energy-related CO_2 emissions (Razali et al., 2016; Gielen et al., 2019). Numerous policies and strategies are available for advanced nations to accomplish their economic, environmental and social objectives. For example, the European Union Energy Performance of Buildings Directive regulates the operational GHG emissions associated with energy use in activities, such as cooling, heating and lighting. In Malaysia, under the green building index (GBI) assessment specifications, green building materials applied to reused and renewed materials in construction have positive impacts on the environment to enhance the performance of buildings and upgrade the effectiveness of indoor air quality (Kuppusamy et al., 2019). However, the regulatory drives have not been extended to the CE linked with the commencing production of building materials.

Sustainable building is a method of ensuring that all construction activities go in the direction of establishing sustainable development while taking environmental, economic and social issues into account (Willar et al., 2021; Ayob et al., 2021). Then, measuring sustainability entails assessing material selection, energy resources, manufacturing processes, design decisions and building sites. The materials selected for sustainable construction are paralleled with the concept of green building and sustainability (Estokova, Vilcekova and Porhincak, 2017; Mattoni et al., 2018). As a result, high embodied impact and sustainable materials indicate a highly sustained building (Pezeshki et al., 2018). CO_2 emissions from materials might be reduced by optimising the LC design in numerous elements, such as product structure layout, material selection and manufacturing processes while considering the overall life cycle performance (Lu et al., 2018).

Green growth is a critical strategy (Balasbaneh and Marsono, 2017) for Malaysia to fulfil its goals of improving economic and societal growth while progressing toward sustainability, as stated in the 11th Malaysian Plan for 2016 to 2020. The Malaysian Carbon Reduction and Environmental Sustainability

Tool (MyCREST) was introduced in 2020 as a performance-based standard that includes carbon assessment indicators and reduction techniques across the life cycle sustainability of a building (Ohueri, Enegbuma and Habil, 2019). MyCREST certification award focuses on three phases of design: building, operation and maintenance and introducing the fundamentals rating scoreboard in the process. The scoring system is a five-star system that ranges from one to five stars. A range of 40% to 49% of the total score is required for one project to receive one star, whereas a score of 80% to 100% is required for a five-star ranking. Earlier, in 2009, the National Green Policy was established and an assessment for environmental practices was initiated through the GBI, anticipating the direction for local practitioners. Currently, green procurement is featured in the national economic planning program. The Green Technology Financial Scheme provides financial incentives to the business sector (Yusof, Awang and Iranmanesh, 2017).

Nonetheless, as compared to neighbouring countries such as Singapore, these paradigm shifts toward green building technology implementation in this country are still in sluggish motion (Ohueri, Enegbuma and Habil, 2019). According to reports from 2018, only 452 buildings used the GBI grading tool and six buildings that used MyCREST were certified green, with the majority of the certified buildings being in Kuala Lumpur. The notion of green procurement, including the use of LC materials, is still relatively new to local CBPs; thus, the lack of understanding in this area should be addressed. Even though certified green tools have been established, national CO_2 emissions are increasing every year, which could be attributable to a mismatch between regulations and project implementation. Despite all efforts to reduce pollutant emissions, Malaysia was categorised as a "very bad" country in terms of CO_2 emission management by the Climate Change Performance Index. Through this index, Malaysia was ranked 53 in 2020, will raise 60% of CO_2 emissions for the year 2200 by maintaining present CO_2 emissions in the building sector, while a 50% reduction will result in a 25% increase in CO_2 by 2200 (Balasbaneh and Marsono, 2017). Even though the number of tools used to calculate the CE level and compare the life cycle environmental impact of products, such as the Environmental Product Declaration (EPD), has risen in recent years, there remains a discrepancy in the data used and the results of different assessments. There are no global benchmarks for materials and credible benchmark exercises are challenging to establish as projects and, to a large extent, site-specific.

A material's practicality, viability and sustainability of a particular material are heavily influenced by site and project category considerations. The lowest CE formula varies depending on structural type and functionality, as well as project to project. The goal of policymakers and authorities in charge of LC materials in construction should be to promote the best alternative for each project. By simply changing several buildings' materials in the structures' element, LC materials could mitigate the environmental impact up to 61% in specific structures and 10.5% in overall projects. The most significant impact is determined not only by the number of built-up materials and the size of the building but also by the type of materials used (Estokova, Vilcekova and Porhincak, 2017). As a result, it is advised to design buildings with a minimal number of materials and to use alternative LC materials in controlling the CE in substructures (Nawarathna et al., 2018). A wide array of considerations should be considered when choosing LC materials, such as the local availability, manufacturing energy intensity, recyclability potential, recyclable constituent, renewability perspective, building waste minimisation, life cycle longevity and maintenance demands (Azari and Abbasabadi, 2018).

Natural-source materials including by-products or recycled content and goods improved through novel manufacturing processes should all be evaluated. Even though no mandatory limit value for material performance has been established, the idea is that designers should strive to enhance their building designs to reduce the negative impact of materials (Alsema et al., 2016).

Resistance to Adopting Alternative Low-Carbon Materials

It is critical to promote a wide range of LC materials at the same time. To overcome client resistance to these novel ideas, buy-in from a wide range of stakeholders is required, including the client who authorises the project, the design group that creates it and the end users who occupy or work in a completed facility. Architects, clients and structural engineers are the CBP groups with a significant impact on material choices (Sarda and Dewalkar, 2016; Lehne and Preston, 2018; Giesekam, Barrett and Taylor, 2018) (as shown in Figure 1). Strategy enhancements such as further design instruction, better marketing and stakeholder engagement, might be necessary to accelerate further sustainable approaches.

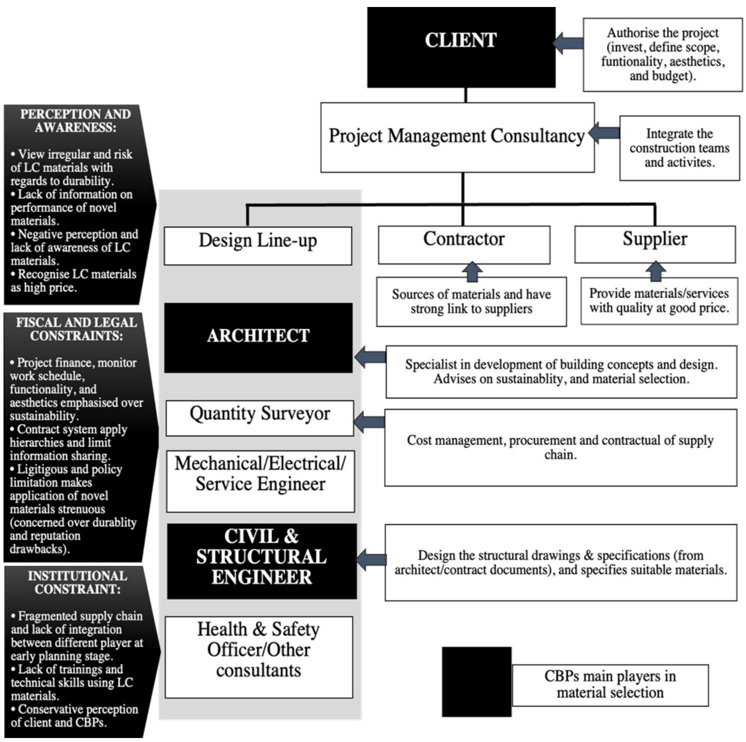

Figure 1. The lineup groups of CBPs involved in the material selection with their perception and constraints

Sources: Adopted from Sarda and Dewalkar (2016), Lehne and Preston (2018) and Giesekam, Barrett and Taylor (2018)

Furthermore, earlier commitment and planning to include LC materials will impact project design and can hamper cost imposts, high-cost adjustments to the design and overall construction program that occur from attempting to minimise CE later in the project timeline (Giesekam, Barrett and Taylor, 2018). Addressing awareness, knowledge and restrictions, for example, is dependent on good-quality information regarding LC materials in less developed countries. On the micro level, many enterprises in these countries including Malaysia, continue to be hampered by an inability to appropriately distribute expertise and learning from project to project. This is because many smaller businesses cannot afford to hire specialised personnel to establish routine processes in CE estimate through incremental learning and knowledge development.

Insufficient understanding permits perceptions and speculation to lead to resistance to LC material solutions. In Malaysia, this scenario is occasionally due to the outdated perception of cost, lack of supportive material performance data and supply. Typically, the cost is prioritised and material sustainability characteristics are less favourable than individuals' knowledge and experience. Often, this reluctance is caused by outdated regulatory requirements that are left behind by the development of technologies and recommend sticking with conventional technology (Razali et al., 2017). Therefore, the challenges in assisting policymakers in adopting LC material solutions and overcoming the constraints need urgent identification to bring forward this country to a sustainable environment.

METHODOLOGY

The research design and questionnaire formulation were established through an extensive literature review, which included determining the title of the research project, problem statement, objectives of the study, research scope and study limitations (as shown in Figure 2).

This research employed a hybrid technique combining qualitative and quantitative modes, including a survey and a series of semi-structured interviews before data analysis with SPSS. This method is widely used in a variety of disciplines and was chosen to anticipate the desired integration of breadth and depth. The design and development of the questionnaire were both influenced by Malaysia's current social, political, economic and technological circumstances. To ensure the originality and avoidance of any hidden accurate information, all survey respondents remained anonymous. A pilot study with 30 experienced CBPs with 10 years to 20 years of experience based in Perlis, Kedah and Pulau Pinang was done.

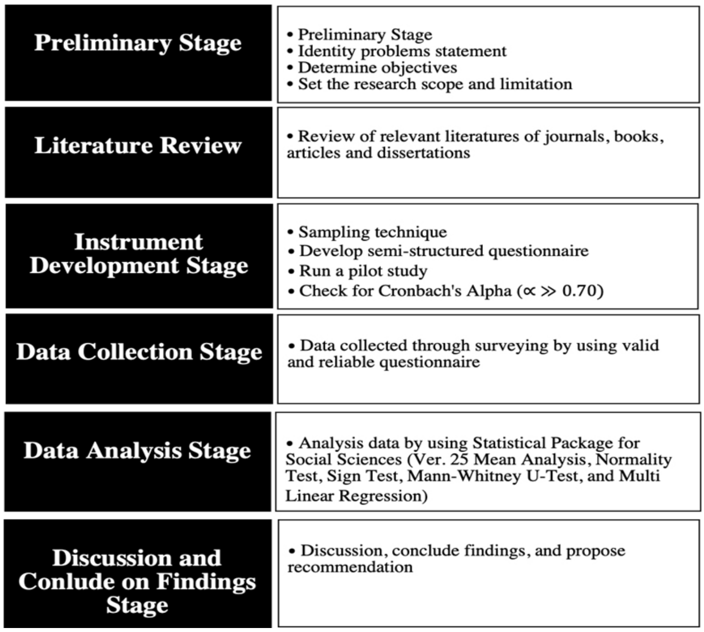

Figure 2. The flow of the research process

This exploratory study provided advanced guidance on the main questionnaire construct in terms of terminology and question flow, as well as the appropriate range of answers, which were later validated to have internal consistency reliability with a Cronbach's alpha score of 0.835. The primary survey was done with a 95% confidence level (as shown in Table 1) based on the Krejcie-Morgan method among 93 enterprises in these specific states (Krejcie and Morgan, 1970).

Table 1. Respondents' companies in Perlis, Kedah and Pulau Pinang

States	**Architects**		**C&S Engineers**	
	Population (*N*)	**Sample Size (*n*)**	**Population (*N*)**	**Sample Size (*n*)**
Perlis	2	2	4	3
Kedah	21	16	36	27
Pulau Pinang	18	14	40	31
Total	41	32	80	61

The Treasury Malaysia Government (2018) information was used to determine the number of CBPs who were greatly involved in material selection, including architect and C&S engineer populations. The four-section questionnaires were disseminated online via email and interviews. The survey would gather preliminary quantitative and qualitative data on material selection, followed by interviews that would examine the highlighted limits in greater depth.

Section A had open-ended questions on demographic information, such as the company they worked for, their experience, the size and a description of projects they had worked on in the past 10 years. To produce trustworthy and legitimate statistics, these data tried to identify the respondents' qualifications. Section B had four close-ended questions about awareness, usage frequency, user experience and material selection drivers (as shown in Table 2). The 12 resources were chosen from a list compiled through a literature review to include both novel and traditional materials. This comprises materials derived from natural sources, materials derived from waste streams and materials propagated through novel manufacturing methods. This does not include a comprehensive lengthy list of the entire LC materials available in the commercial construction industry.

Table 2. Type of LC materials

LC Materials
Precast hollowcore floor slab (Precast HFS)
Structural insulated panel (SI panel)
Glue laminated timber (GL timber)
Ground granulated blast furnace slag (GGBS)
Pulverized fuel ash (PF ash)
Unfired brick (UF brick)
Geopolymer concrete (GP con)
Concrete containing construction and demolition wastes (Con-CDW)
Concrete containing agricultural wastes (Con-AW)
Rammed earth (RE)
Reclaimed timber (RC timber)
Recycle aggregates (RA)

The first question asked respondents to demonstrate their understanding of LC materials with responses such as "Not aware", "Aware of but not used" and "Aware and used in the project(s)". The second, third and fourth questions were created for responders who had marked "Aware and used in the project(s)" in the preceding question. Concerning the frequency of material use, four options were presented: "Least often", "Often", "Very often" and "Most often". The third question asked respondents to characterise their experience with LC materials by selecting one of four responses: "Not favour and will not use again", "Somewhat not favour", "Somewhat favour" and "Favour and will use again". The fourth question addressed the factors influencing material choices for their projects. Respondents might highlight the options of "Not relevant", "Least relevant", "Relevant" and "Very relevant". Sections C and D asked respondents about the 12 constraints and possible solutions for LC material acceptance and they may select "Not important", "Least important", "Important" and "Very important" (as shown in Table 3).

Table 3. Factor analysis of rotated internal constraints groups component matrix

Constraints	Rotated Group Component Matrix		
	G1-Management	G2-CBP-Related-Constraints	G3-LC Material Related-Issue
Perception of the extra cost being incurred	0.881		
Perception of extra time being incurred	0.818		
Limited availability of supplier	0.676		
Lack of sustainable materials information	0.617	0.436	
Lack of regulation		0.772	
Lack of comprehensive tools and data to compare material alternatives		0.706	
Lack of design knowledge and skills	0.491	0.689	
Unwilling to change to the conventional way of specifying		0.687	
Low flexibility of alternatives or substitutes	0.515	0.560	
The perception that sustainable materials are low in quality			0.781
Maintenance concern			0.760
Aesthetically less pleasing			0.756
Extraction method: Principal component analysis			
Rotation method: Varimax with Kaiser normalisation			
Rotation converged in five iterations			

Following that, a normality test was performed to establish whether the data sets linked with the perspective of CBPs of LC materials (Section B) fit a normal distribution model. The outcome indicated that the null hypothesis (H_0) was rejected. As a result, the acquired data set was declared not normally distributed and was analysed using the nonparametric procedures of the sign test (ST) and Mann-Whitney U test (MWUT). Due to its robustness, the parametric method of multiple linear regression (MLR) was also employed. For all four questions, ST used an adjusted Likert-scaled score provided by respondents (in Section B).

Simultaneously, MWUT was used to statistically assess the score dependency between the two groups of architects and C&S engineers. The MLR model was used to forecast the connection between one continuous dependent variable (awareness level, usage frequency, use experience, material selection drivers) and two independent variables (experience of CBPs and company size). The current study established a standard of 60% for CBPs to be classified as having high levels of awareness, usage frequency, user experience and material selection drivers. To simplify the calculation in other analyses, factor analysis was employed in Section C to consolidate some of the groups of constraints into many larger groups (as shown in Table 3).

RESULTS AND DISCUSSION

Demographic Information

The total response rate was 79.57% from 93 organizations, with 30 (40.54%) responding architects and 44 (59.46%) C&S engineers. Each company was represented by one or more CBPs who completed the main questionnaire (Google Form) and were interviewed online. Figure 3 depicts demographic information in detail.

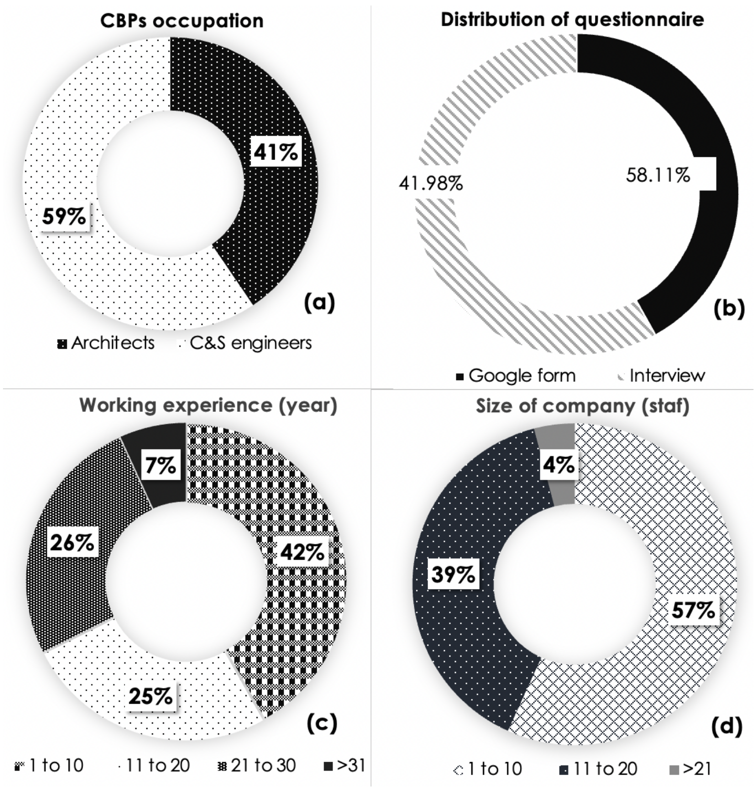

Figure 3. Demographic information of respondents' profiles of: (a) CBPs occupation, (b) Method of distribution of the questionnaire, (c) Working experience and (d) Size of the company

The Perspective of CBPs on Awareness, Usage Frequency, Use Experience and Drivers for Material Selection

The results revealed that 51.4%, 50.0% and 29.7% of participants responded "Aware and used in the project(s)" for UF bricks, precast HFS and SI panels, respectively (as shown in Table 4).

Table 4. Awareness of CBPs on LC materials

Type of LC Materials	Not Aware (%)	Aware Of but Not Used (%)	Aware and Used in the Project(S) (%)	Mean	Standard Deviation (SD)
UF brick	16.2	32.4	51.4	2.35	0.748
Precast HFS	1.4	48.6	50.0	2.49	0.530
SI panel	5.4	64.9	29.7	2.24	0.544
Glue timber	16.2	54.1	29.7	2.14	0.669
GP con	33.8	50.0	16.2	1.82	0.690
Con-CDW	25.7	58.1	16.2	1.91	0.645
Con-AW	25.7	58.1	16.2	1.91	0.645
RC timber	23.0	63.5	13.5	1.91	0.601
RA	12.2	74.3	13.5	2.01	0.510
PF ash	47.3	40.5	12.2	1.65	0.691
RE	44.6	44.6	10.8	1.91	0.645
GGBS	51.4	37.8	10.8	1.59	0.681

This finding is not surprising given how common and widely used these LC materials are in projects. UF bricks have comparable conductivities to fired brick products and are more vapour permeable, which can improve indoor air quality. When compared to its counterpart, the production of UF bricks emits 80% less CO_2 into the atmosphere and its end-of-life impact is much lower because it can be recycled with minimal energy use (Muheise-Araalia and Pavia, 2021). Reclaimed products and alternative concrete materials are more commonly used than unconventional materials such as GL timber. According to Ohueri, Enegbuma and Habil (2019), these findings were lower than the public awareness of the impact of climate on Singaporeans (94.9%) and those respondents (95.4%) strongly support Singapore's transition to an LC economy (National Climate Change Secretariat Singapore, 2019). According to replies in Table 5, UF bricks (16.2%) were the most considered LC materials, followed by precast HFS and SI panels at 13.5% and 9.5%, respectively.

Table 5. Usage frequency of LC materials

Type of LC Materials	Least Often (%)	Often (%)	Very Often (%)	Most Often (%)	Mean	SD
UF brick	52.7	21.6	9.5	16.2	1.89	1.130
Precast HFS	50.0	21.6	14.9	13.5	1.92	1.095
SI panel	68.9	13.5	8.1	9.5	1.58	0.993
Glue timber	71.6	16.2	9.5	2.7	1.43	0.778
Con-CDW	82.4	10.8	4.1	2.7	1.27	0.668
Con-AW	83.8	8.1	5.4	2.7	1.27	0.668
GP con	83.8	6.7	8.1	1.4	1.27	0.668
RE	86.4	10.8	1.4	1.4	1.18	0.506
RC timber	83.8	13.5	1.4	1.4	1.20	0.523
GGBS	86.4	9.1	3.1	1.4	1.15	1.222
PF ash	86.6	9.5	2.6	1.3	1.19	0.541
RA	86.5	12.1	1.4	–	1.15	0.395

GGBS, PF ash and RE were the LC materials that were rarely employed in projects, which could be because of unfamiliarity, poor performance and negative perceptions of local practitioners. During interviews, some CBPs stated that clients would reject these alternative materials because they do not see a good deal on the principal condition, even though they can save money on the overall project cost.

Academics contend that this result aligns and coincides with their findings from relevant literature reviewed on the driving influences of sustainable construction (Giesekam, Barrett and Taylor, 2015; Chan, Masrom and Yasin, 2022). In this case, the misconception that LC materials are expensive should be rectified by providing all stakeholders with accurate and verified information on the benefits of CE in the construction sector, particularly in terms of reducing the environmental impacts of CE. As a result, incorporating such materials into designs is a significant initial approach, indicating lower cost changes to the construction programme and better off limitations of principal cost (Aslam, Baffoe-Twum and Saleem, 2019).

Table 6 depicts three types of LC materials that had a positive impact on respondents and that they will consider using in future projects, despite having only used them in one of their projects. The most favourable SI panels marked the highest (40.9%), followed by precast HFS (40.5%) and UF bricks (30.0%). Client requirements (44.6%), regulatory requirements (37.8%) and saving construction time (37.8%) (as shown in Table 7) were among the relevant factors driving CBP to use LC materials in their construction projects.

Table 6. Experience use of LC materials

Type of LC Materials	Not Favour and Will Not Consider Again (%)	Somewhat Not Favour (%)	Somewhat Favour (%)	Favour and Will Consider Again (%)	Mean	SD
SI panel	–	–	59.1	40.9	1.01	1.590
Precast HFS	2.8	2.8	53.9	40.5	1.66	1.74
UF brick	5.0	–	65.0	30.0	1.73	1.682
RA	–	–	80.0	20.0	0.43	1.110
Con-CDW	–	16.6	66.7	16.7	0.49	1.140
Con-AW	–	33.3	50.0	16.7	0.46	1.090
GGBS	–	22.1	66.4	11.5	0.35	0.970
PF ash	55.3	–	33.3	11.4	0.31	0.880
Glue timber	9.5	9.5	71.5	9.5	0.80	1.330
RE	–	–	100.0	–	0.32	0.938
GP concrete	16.5	8.6	74.9	–	0.42	1.010
RC timber	–	89.7	10.3	–	0.42	1.070

Table 7. Drivers of LC material selection

Drivers	Not Relevant (%)	Least Relevant (%)	Relevant (%)	Very Relevant (%)	Mean	SD
Client requirement	12.2	10.8	32.4	44.6	3.09	1.023
Regulatory requirement	4.1	13.5	44.6	37.8	3.16	0.811
Save time on construction	4.1	20.3	37.8	37.8	3.09	0.863
Save operation cost	2.7	23.0	39.2	35.1	3.07	0.833
Often looking for new technology/innovation	4.1	6.7	56.8	32.4	3.18	0.728
Enhanced health and safety system	5.4	16.3	45.9	32.4	3.05	0.842
Consultants required the material	6.8	16.2	48.6	31.1	3.03	0.860
LC materials are more economic	6.8	16.2	48.6	28.4	2.99	0.852

(Continued on next page)

Table 7. *Continued*

Drivers	Not Relevant (%)	Least Relevant (%)	Relevant (%)	Very Relevant (%)	Mean	SD
Earned points towards the green building Assessment Scheme	12.2	18.9	41.9	27.0	2.84	0.966
Provided the best structural performance	4.1	17.5	54.1	24.3	2.99	0.767
Felt morally obliged to use LC materials	9.5	9.5	58.1	23.0	2.95	0.842
Preferable aesthetic	5.4	29.7	47.3	17.6	2.77	0.803
Suitable with company principle	13.5	20.3	52.7	13.5	2.66	0.880

In practice, it is difficult to assign responsibility for material selection and CE reduction to a single group because many players influence project decisions with a focus on duty to ensure a consistent connection to the completed building. The industry's reluctance to adopt alternative materials stems primarily from its risk-averse and litigious values. To ensure the full support of CBPs and given that clients are in a strong position to steer CE assessment and do not require authorising legislation, they could assign a personnel development team to monitor CE throughout the project, hold all groups accountable and spell out the terms in the contract structure. Furthermore, regulators believe that extreme rather than incremental change is required to meet targets, which can increase the focus on CE in this sector. For example, incorporating embodied carbon regulation of new facilities into Malaysia's mandatory GHG emission reporting conditions for listed firms and expanding this instruction to include additional companies. Local governments can establish their mandatory planning instructions and provide financial incentives, such as reduced council tax for exemplary LC properties.

Clients in the public sector, such as the Department of Work (DOW), can set an example by mandating embodied carbon assessments and encouraging the use of alternative LC materials on public projects. Fundamental changes in governmental sector attitudes, as well as the establishment of regulatory requirements, will be required to steer this change across the country. Furthermore, government policy and enforcement, providing sufficient information to clients and providing incentives at the early design stage are the main roles to push stakeholders' participation in LC materials enhancement in Malaysia.

For the statistical analysis of ST, the hypothesis was tested based on the statement of H_0: median = 60% and H_1: median ≠ 60%. The result revealed the P-value ≈ 0.000 < α = 0.05 (as shown in Table 8). As a result, H_0 was rejected.

Table 8. Frequencies of ST

Frequencies (*N*)		**Test Statistics**
Median score		Asymp. Sig. (2-tailed), *P*
Negative differences	5	0.000
Positive differences	68	a. Sign test
Ties	1	
Total		
Median < Score		
Median < Score		
Median = Score		

The majority of the companies (68 out of 75) scored lower than the benchmark score (60%). As a result, we are 95% confident that the awareness, usage frequency, user experience and material selection drivers for architects and C&S engineers remain low. Next, the MWU test was conducted under the hypothesis of H_0: $median_1 - median_2 = 0$ and H_1: $median_1 - median_2 \neq 0$. The *P*-value was 0.46, which was more than a = 0.05 and resulted in failing to reject H_0. As a result, we are 95% confident that there is no difference between the two types of professional occupations in terms of awareness, usage frequency, use experience and material selection drivers. In this case, their perception is still at a low level.

As for MLR, before proceeding with the main analysis, this study conducted tests on its assumption to ensure that the model developed through the data collected is valid. The assumptions were met; thus, MLR was used to analyse the data. The value of R^2 was 0.009 (< 1%), which implied that the year of working experience of CBPs in the particular field and the size of their company did not help explain their awareness, usage frequency, use experience and drivers for the selection of LC materials. Consistently, the hypothesis testing on the relationship of dependent variables with years of working experience and the size of the company showed that they had no relationship with awareness level, usage frequency, use experience and drivers for the selection of LC materials. Basically, with 95% confidence, we can say that more years of working experience with CBPs and a larger company do not necessarily impose a significant influence on the use of LC materials.

Constraints to LC Material Selection

The CBPs identified "Lack of sustainable material information" (44.9%), "Lack of design knowledge and skills" (35.8%) and "Maintenance concern" (19.6%) as significant constraints from the three management groups, CBPs-related issues and LC material-related issues (as shown in Table 9).

Table 9. Constraints in LC material selection

Constraints	Not Important (%)	Least Important (%)	Important (%)	Very Important (%)	Mean	SD
G1-Management						
Lack of sustainable material information	3.7	13.2	38.2	44.9	3.07	1.021
Perception of the extra cost being incurred	8.1	18.3	37.8	35.8	2.82	0.863
Perception of extra time being incurred	5.9	19.4	39.6	35.1	3.05	0.833
Limited availability of supplier	4.1	6.7	56.8	32.4	2.85	0.728
G2-CBP Related Issues						
Lack of design knowledge and skills	2.8	20.2	38.5	38.5	3.03	0.890
Lack of comprehensive tools and data to compare material alternative	9.8	13.2	38.6	38.4	2.99	0.852
Unwilling to change the conventional way of specifying	4.1	21.7	39.1	35.1	2.77	0.767
Low flexibility of alternative or substitutes	12.2	18.9	47.9	21.0	2.74	0.966
G3-LC Material Issues						
Maintenance concern	5.4	27.7	47.3	19.6	2.82	0.803
Aesthetically less pleasing	8.5	28.3	47.5	15.7	2.58	0.842
The perception that sustainable materials are low in quality	11.5	20.3	52.7	15.5	2.56	0.880

To reduce uncertainty and risk, this industry relies on proven technology and innovation; thus, benchmark data or samples from previous projects are required to provide confidence. In this location, it is still difficult to obtain reliable information from product makers with consistent data sets on CE, as there are no active projects to serve as proof points. In addition, LC materials frequently perform similarly to the material they are replacing and the only distinction is the methods by which they are manufactured. To secure and confirm the LC credentials of products, EPD and other third-party certification procedures must be used urgently (Lehne and Preston, 2018).

Additionally, it is challenging to conduct a trial in these states; a case study of new building items and technologies demonstrated their relative newness in the market. The display of small-scale LC construction products from manufacturers not only increases the relevance of LC materials but also competes with current market leaders and unleashes supply chain innovation. Due to a lack of design knowledge and skills, many CBPs are unsure how to interpret the information presented within carbon reduction tools or EPD in specifications and standards. To challenge contemporary material specifications and standards, as well as upskill subcontractors to obtain adequate materials, time, funding and investments are required. Standard specifications relied on by the local market in this region commonly do not include low embodied carbon stipulation. This is consistent with the current findings of Chan, Masrom and Yasin (2022), which concluded that the use of LC materials is dependent on the type of project, design purpose, assembly cost and future maintenance due to the uncertain technicality of those materials. The results for the second-ranked constraint are consistent with earlier research that strongly suggested that sustainability in building construction should start with the planning stage and be reflected in the design (Maqbool and Amaechi, 2022; Hwang and Tan, 2012; Giesekam, Barrett and Taylor, 2018).

Due to the gaps in the study's findings, the DOW and the Construction Industry Development Board (CIDB) for instance, improve their efforts to measure and lessen the effects of the built environment in terms of environmental implication and CE from the materials used by taking a more thorough approach to the integration of socio-economic sustainability directions to the built environment and construction development in Malaysia. CBPs are encouraged to support MyCREST in integrating the design process, as collaborative design promotes green building developments, LC materials and improved building sustainability. Furthermore, CBPs should use the carbon assessment method and metrics that are integrated into the sustainable framework of the MyCREST scoreboard, making it a unique tool for quantifying the CE of materials and thus facilitating the achievement of Malaysia's sustainable development goals.

Alternative Solutions

To improve the application and acceptance of LC materials in this industry, participants gave high ratings to "Training on designing a building with LC materials" (43.2%), "Clear regulation on limiting CE in construction" (39.2%) and "Increase demonstration of projects and case studies" (36.5%) (as shown in Table 10).

Table 10. Alternative solutions for LC material adaption and acceptance

Alternative Solutions	Not Important (%)	Least Important (%)	Important (%)	Very Important (%)	Mean	SD
Training on designing buildings with LC materials	1.4	6.8	48.6	43.2	3.34	0.668
Clear regulation of limiting CE in construction	1.4	5.4	54.0	39.2	3.31	0.639

(Continued on next page)

Table 10. *Continued*

Alternative Solutions	Not Important (%)	Least Important (%)	Important (%)	Very Important (%)	Mean	SD
Increase demonstration of projects and case studies	2.7	2.7	58.1	36.5	3.28	0.652
More information on material performance and design	1.4	8.1	58.1	32.4	3.22	0.647
Increase environmental awareness to CBPs	2.7	6.8	58.1	32.4	3.20	0.682
Reduce LC material cost	1.4	9.5	56.7	32.4	3.20	0.662
Higher value in assessment schemes	1.4	9.5	64.8	24.3	3.12	0.618

Training and design tools for evaluating LC design solutions will raise awareness, which will influence decisions in driving CE eradication. Better design decisions for highly sustainable project material selection are typically appraised earlier. Early training engagement will prevent the need for expensive redesign. Furthermore, CBPs can develop design specifications that favour lower CE intensities for products containing large volumes of materials, such as cement, concrete, steel and aluminium (Giesekam, Barrett and Taylor, 2018). Moreover, the development of training and skill programs for LC materials, measurements, methods and procedures as well as links to professional certificate credits within engineering and architectural specialisations, will inspire and boost confidence among professional practitioners.

The regulatory mandate, policy stability and political backing allow this industry to seriously explore adopting sustainable alternatives and emphasising low CE standards to get a unified voice from authorities. The DOW and CIDB can continue to create a benchmarking approach for CE assessment and acceptance. These organisations can collaborate with researchers to offer support and viewpoints where knowledge gaps occur. The government through affiliated research organisations, may provide funding for initiatives to develop important data sources for CBPs, such as Life Cycle Inventory data for this country. Additionally, professional institutes can play a role by offering the necessary legitimacy. For instance, the IEM can improve the Malaysian Structural Eurocode, such as in MS: EN 1992: Eurocode 2 Design of Concrete structure, which aims to minimise embodied carbon. These professional organisations can facilitate knowledge transfers between firms, support the development of an LC materials community, aid in addressing the current skills gap via training courses, provide financing for demonstration projects and examine LC materials. In these specific states, case studies and project demonstrations can be used to provide more success stories about low CE solutions. Sharing the uncertainty and risk description across all participants will permit new LC materials and innovation to be practical at the procurement stage during these events.

CONCLUSION

The major goal of this study is to comprehend the viewpoints that prevent CBPs from adopting various materials that are commonly thought to contain less embodied carbon. The findings of this study indicate that architects and C&S engineers in Malaysia's northern region still have poor levels of awareness, usage frequency, use experience and material selection drivers. The CBPs are hindered by a lack of design knowledge and expertise as well as a dearth of understanding about sustainable materials. To address these issues, it will be necessary to provide additional training in designing buildings using LC materials, establish clear regulations limiting the use of these materials in projects and engage firmly in CE assessment with appropriate systems in place, such as modifications to contracts and tender documents. This will guarantee that awareness and knowledge are spread internally and from project to project. The CBPs of these states should work with government associates on upcoming government-driven projects. Furthermore, Malaysian government communication and awareness, as well as holistic coordination between LC, technology-based and nature-based solutions, are required for this transition to take place. Finally, raising awareness of the significance of CE in addressing sustainability in the construction industry will be achieved through shared embodied goals across the value chain and collective commitments of organisational targets.

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