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Perception of Embodied Carbon Mitigation Strategies: The Case of Sri Lankan Construction Industry

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Abstract: Whilst operational carbon (OC) emission reduction has received greater attention in the literature, embodied carbon (EC) emission reduction aspect has been largely neglected. This is particularly seen in developing countries. This study assessed the awareness and perception of carbon emission in general and EC emission reduction strategies in particular in the Sri Lankan construction industry. A detailed questionnaire, based on a comprehensive literature review, was developed to assess the awareness and perception of the Sri Lankan construction professionals about global carbon emissions, OC emissions, and EC emissions and carbon mitigation strategies. Based on a sample of 111 professionals in the construction sector, results revealed that the Sri Lankan construction professionals have poor awareness about carbon emission, especially about EC emission and EC mitigation strategies. The results further revealed that they are more concerned about the OC emission reduction than the EC emission reduction. The results suggest that they are basically aware of some basic/conventional mitigation strategies such as better design (low-carbon), an extension of building life and refurbishment of existing buildings and carbon tax, but their awareness of recently introduced micro-level technologies/strategies is significantly poor. Findings are a clear reflection of the current situation in many developing countries with regard to carbon emission and mitigation strategies. It was found that a major reason for low awareness was related to the culture: The majority of the respondents believed that actions to reduce carbon footprint should be initiated and handled by the government and other authorities, but not by construction professionals.

Keywords: embodied carbon emissions; operational carbon emission; mitigation strategies; construction; Sri Lanka

1. Introduction

Global warming is the most serious environmental issue that the global community has to address in the 21st century [1]. According to a special report of emission scenarios (SRES), the global temperature is predicted to increase in the range 1.4°C to 5.8°C between 1990 and 2100 [2]. A major reason for this temperature change is the continuous increase in greenhouse gas (GHG) levels in the atmosphere. Among various gases, CO_2 accounts for 9–26% of total GHG emissions [3]. World cities, which occupy only 3% of the earth's land mass accounts for more than 75% of carbon emissions. The building sector, which accounts for 40% of the total global energy consumption and 30% of the total global carbon emissions, is recognized as one of the most significant contributors to the global carbon emissions [4]. The building sector, therefore, has the largest potential to mitigate carbon emissions [5].

There have been significant efforts by both policymakers and academics across the globe to understand and mitigate CO_2 emissions emanating especially from the operational stage of buildings.

These efforts, in turn, are expected to result in more energy efficient buildings. However, more energy efficient buildings, it is argued, may indirectly result in more CO_2 emissions, especially more embodied carbon (EC) emissions. For example, Dixit, Fernández-Solís [6] mentioned that for a new, well insulated, and energy efficient building embodied energy use can even exceed the operational energy use in that building. According to Crawford [7], if embodied emissions are neglected further, embodied emission level could even reach up to 50% of the total global carbon emissions. However, not much effort has been made to understand and analyze how to mitigate EC emissions. Pomponi and Moncaster [8] stated that studies investigating embodied carbon reduction and mitigation strategies are very limited in the literature. This issue has been particularly severe in developing countries.

Similar to many other developing countries, the construction industry in Sri Lanka has a significant impact on the environment. With the building sector accounting for more than half of the raw material used in construction and 35% of the national energy, it is evident that the building sector contributes to a significant portion of CO_2 emissions in Sri Lanka [5]. The recent rapid increase in construction activities in the Sri Lankan construction industry, especially commercial and residential projects in Colombo suburbs is likely to have a significant impact on the environment. Even though Kumanayake and Luo [5] stated that the Sri Lankan construction sector has identified the need to mitigate operational carbon emissions, EC emission aspect has been largely neglected by the Sri Lankan construction sector. The Sri Lankan construction stakeholders have begun to adopt various strategies to mitigate the operational carbon emissions. However, as discussed above, the heavy focus on operational carbon (OC) mitigation may increase the embodied carbon (EC) emissions from construction projects. Like in many developing countries, research on EC emissions of the construction sector is very limited in Sri Lanka.

A possible reason why embodied carbon aspect has been largely ignored by researchers and other relevant authorities could be the lack of awareness on the importance of embodied carbon. This study aims to investigate the perception of construction professionals on awareness and the significance of embodied carbon mitigation strategies and their adaptability to the Sri Lankan construction industry. The Sri Lankan construction industry is an ideal case for this study as there has been a heavy focus on operational emission reduction, and largely neglecting the embodied emission aspect. On the other hand, as there is a rapid increase in construction activities, this is the ideal time to emphasize the importance of the embodied carbon mitigation strategies in designing new developments. Therefore, an awareness assessment of Sri Lankan construction professionals regarding the current situation of embodied carbon emissions and the mitigation strategies is timely. This study provides an insight into the perception and awareness of the Sri Lankan construction professionals about embodied carbon emissions and promotes embodied carbon mitigation strategies. This study will be of significant importance in enhancing awareness among professionals in achieving the long-term sustainability goals. The findings will provide the necessary impetus to enhance the awareness of the Sri Lankan construction professionals on the available carbon mitigation strategies. The structure of the study is as follows. Following section reviews the literature on the current trend of carbon emissions in the Sri Lankan construction industry and the use of embodied carbon mitigation strategies across the globe. The methodology section then describes the questionnaire survey and the data collection process, followed by the empirical analysis. Finally, the conclusions and further research directions are drawn.

2. Literature Review

The construction industry is recognized as a major beneficiary of the rapid economic development in Sri Lanka that has effected since the end of civil war in 2009. The rapid increase in the development of infrastructure and high-end commercial, residential, and hotels has resulted in a boom in the Sri Lankan construction industry. According to National Development Bank securities, a private brokerage based in Colombo, the growth of Sri Lankan construction industry has been as twice as the GDP growth of the country since 2009. As seen in Table 1, the number of total construction activities has increased by 57%, while residential construction activities have been increased by more than 100% during 2010 and 2015 period. The correct number of projects would be even higher as some construction projects in the country may not have been registered in the Department of Census, Sri Lanka. The construction sector has thus become one of the major industries that consume a large number of materials and energy in Sri Lanka. According to Kumanayake, Luo [9], the global construction sector accounts for nearly 40% of the global energy consumption and similarly, the Sri Lankan construction industry accounts for 35% of the national energy consumption in Sri Lanka [9]. The construction sector is also considered as the largest material consumer in the world in 2005 [10] and similarly, the building sector accounts for nearly 50% of the raw material used in Sri Lanka [5].

Table 1. Registered construction activities in Sri Lanka: 2007–2015.

Year	No. of Residential Construction Activities	No. of Non-Residential Construction Activities	No. of Additions and Alterations	Total Number of Activities
2007	423	1965	811	3199
2008	57	447	109	613
2010	374	1453	953	2780
2012	243	1833	614	2690
2014	955	2006	461	3422
2015	757	2941	664	4362

Source: Department of Census and Statistics (2015).

The construction sector accounts for one-third of global carbon emissions due to the high level of material and energy consumption. The construction sector was responsible for 18% of the global carbon emissions [11], and has been recognized as a major contributor to GHG emissions [4]. United Nations Environmental Program [UNEP] [12] reported that building sector accounts for 40% of the total global energy consumption resulting in nearly 30% of the total global CO2 emissions. According to Kumanayake et. al [9], the Sri Lankan building sector is also a major contributor to GHG emissions. It is evident in Figure 1 that the percentage of carbon emissions in the building sector has significantly increased over the past two decades. In 1975, the Sri Lankan building sector accounted for zero CO_2 emissions, but this has increased up to 4.08% in 2013. This is expected to increase even further with multiple construction projects taking place in Sri Lanka.

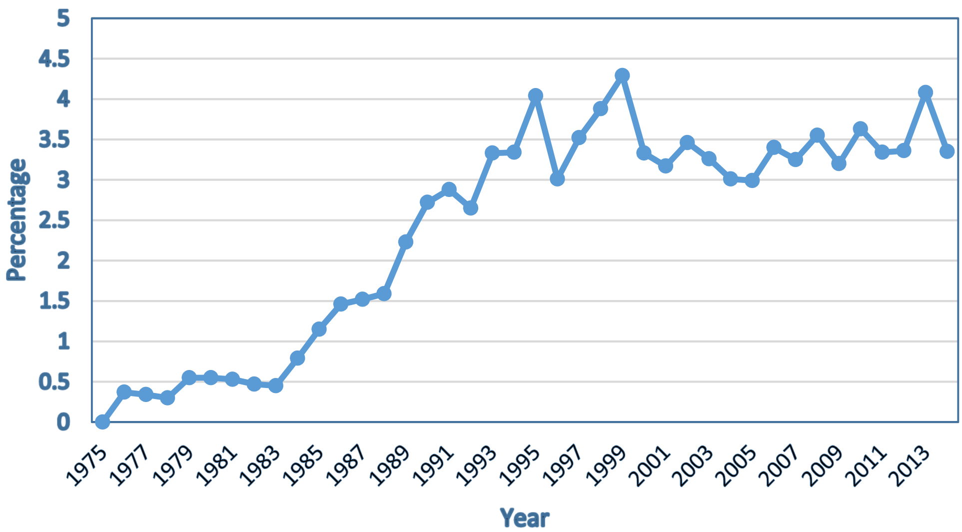

Figure 1. CO_2 emissions from residential, commercial and public services buildings (% of total fuel combustion) in Sri Lanka (Source: IEA Statistics © OECD/IEA 2014 (http://www.iea.org/stats/index.asp).

There have been significant efforts both by policymakers and academics across the globe to study and mitigate CO_2 emissions emanating especially from the operational stage (operational carbon) of buildings. These efforts, in turn, are expected to result in more energy efficient buildings. However, more energy efficient buildings, it is argued, may indirectly result in more CO_2 emissions, especially more EC emissions. For example, Dixit, Fernández-Solís [6] mentioned that for a new, well insulated and energy efficient building, the embodied energy use can even exceed the operational energy use. Nevertheless, not much effort has been made to understand and analyze how to mitigate embodied carbon emissions. Pomponi and Moncaster [8] stated that studies investigating embodied carbon reduction and mitigation strategies are very limited in the literature. This issue has been particularly apparent in developing countries because of the short-term financial benefits that bring through operational energy reduction. Thus, the industry practitioners in these countries tend to focus more on the operational aspect of buildings and largely ignore the embodied aspect.

A recent study has revealed that embodied energy accounts for 5–10% of the whole life cycle energy of a building [13]. Another recent study reported that the embodied carbon emissions account for 10–97% whole life-cycle carbon emissions in a building [14]. This amount is likely to rise when shifting from conventional to zero energy buildings, which is now the practice around the world. In 2005, the construction sector accounted for 11.7% of Ireland's national emissions and out of that, 71% were from embodied sources [15]. Huang and Bohne [16] stated that construction emissions in Norway reported a significant rise from 4.2 Mt CO_2e in 2003 to 5.3 Mt CO_2e in 2007. They further mentioned that a major portion of the emission was embodied emission. According to Chang, Zuo [17], nearly 50% of China's total energy was consumed by the construction industry. They further stated that materials, electricity supply, heating and fuels as the largest contributor to the embodied energy consumption in China. In 2009, the construction industry accounted for 66.5% of the total carbon emissions in China, out of which, 96.6% were embodied emissions [18]. Therefore, it is clear that the embodied carbon emission from the building sector is increasing considerably. This is very much the case in the Sri Lankan building sector. Though Sri Lankan construction practitioners have started taking some measures to reduce operational carbon emissions, embodied emission aspect has been largely neglected due to numerous reasons. Installation of high efficient electrical systems, maximizing the use of natural lighting and ventilation in building designs, adopting green building certifications and reducing energy use are some of the measures adopted by the Sri Lankan construction practitioners to reduce operational carbon emissions. Some possible reasons to not identify the sources and impacts of embodies carbon emissions could be the lack of studies available on embodied carbon emissions, as well as lack of awareness about embodied emissions, especially in the Sri Lankan context.

Embodied Carbon Mitigation Strategies

Embodied carbon mitigation has become an increasingly popular area of research in the carbon emission related research domain. As a result, several inventories have been developed to monitor the typical embodied energy and carbon emissions of construction materials and activities which will enable the users to quantify the impact on environment [19]. Despite the unavailability of a standard protocol to estimate embodied carbon emissions, strong quantitative methodologies have enabled the researchers to successfully estimate embodied carbon emissions of construction activities, which has resulted in moving to the next step of the process, embodied carbon mitigation [14]. There are numerous measures to mitigate carbon emissions during various stages of a project. These stages mainly include the design and construction phases of the project [8], operation phase [20] and the end of life phase [21]. A significant focus has been given to the GHG emission reduction in the operation phase and a considerable amount of research work has been done in finding ways to mitigate emissions during this phase. However, studies on embodied carbon mitigation strategies are considerably limited in the literature. Pomponi and Moncaster [8] have reviewed a number of studies available on embodied carbon emissions and listed out 17 embodied carbon mitigation strategies: (i) Practical guidelines for a wider use of low-EC materials, (ii) better design, (iii) reduction, re-use and recovery of EE/EC intensive construction materials, (iv) tools, methods, and methodologies, (v) policy and regulations (Governments), (vi) refurbishment of existing buildings instead of new built, (vii) Decarbonization of energy supply/grid, (viii) inclusion of waste, by-product, used materials into building materials, (ix) increased use of local materials, (x) policy and regulations (construction sector), (xi) people-driven change (key role of all built environment stakeholders), (xii) more efficient construction processes/techniques, (xiii) carbon mitigation offsets emissions trading, and carbon tax, (xiv) carbon sequestration, (xv) extending the building's life, (xvi) increased use of prefabricated elements/off-site manufacturing, and (xvii) demolition and rebuild. These seventeen strategies can be considered as significant measures to mitigate embodied carbon emissions from the building sector. The present study uses these strategies to evaluate the awareness of Sri Lankan construction professionals on embodied carbon mitigation strategies. Despite the availability of research studies to identify and introduce embodied carbon mitigation strategies to construction professionals in developed countries, there is a severe scarcity of related research studies in developing countries. This has been further confirmed by the studies conducted by Kofoworola and Gheewala [22], Ramesh et al. [23], Varun et al. [24], Paulsen and Sposto [25], Pinky Devi and Palaniappan [26], and Wen et al. [27], who state that most of the studies on carbon emissions and mitigation have been conducted in developed countries resulting in a scarcity of studies in developing countries.

3. Research Methodology

A mixed methods triangulation approach was used, which combines a comprehensive literature review, a questionnaire survey with 111 professionals followed by another semi-structured questionnaire survey with 31 senior professionals chosen from the same sample working in the Sri Lankan construction industry. Previous researchers adopted and highlighted the benefits of using mixed methods research design in the construction engineering and management field [28–31]. Triangulation, simultaneously using multiple research methods, is a valuable strategy in the research process, and the mix methods will complement the strengths and weaknesses of other methods [32]. A comprehensive literature review was conducted to identify the global trend of carbon emissions and mitigation strategies. This helped to compile a comprehensive questionnaire, which covered practices and perceptions, as well as the importance of GHG emissions from the construction industry. The literature review also helped to identify 17 embodied carbon mitigation strategies, which were used in the questionnaire to assess the awareness of these strategies among the Sri Lankan constriction professionals. The main purpose of the structured questionnaire survey was to assess the awareness of Sri Lankan construction professionals on GHG emissions and embodied carbon mitigation strategies. The second questionnaire survey was administered among a limited group of professionals, drawn from the same sample, to understand the reasons for their limited knowledge about the carbon emissions, especially embodied carbon emissions and mitigation strategies.

Prior to the questionnaire survey, a pilot study was conducted with three industry experts with more than 10 years of working experience to fine-tune the full questionnaire. This helped the research team to ensure that the instructions and questions were clear to the prospective respondents. Upon fine-tuning the questionnaire based on the pilot study, both online and paper-based questionnaire surveys were administered, during July—October 2018 among the industry practitioners (professionals). The questionnaire consisted of four sections. The first part of the questionnaire collected the demographic information of the respondents. The second section aimed to assess the knowledge, awareness, and perception of the respondents about carbon emissions, embodied carbon emissions and operational carbon emissions. The third section of the questionnaire consisted of several statements on carbon emissions to further assess the awareness of the respondents. Section four of the questionnaire has two main parts: Part (1) assessed the awareness of respondents about the 17 carbon mitigation strategies identified through the literature review, while part (2) assessed their perception towards the importance of those mitigation strategies.

The respondents were asked to rank their degree of awareness, and their perception towards the importance based on a five point-Likert scale. Accordingly, awareness was scaled as 1 = "very low awareness and knowledge" and 5 = "high awareness and knowledge", and the perception was scaled as 1 = "totally disagree" and 5 = "totally agree". Previous researchers have used different rating scales ranging from four points to eleven points [33–35]. In this study, however, a five-point Likert scale was considered more suitable. The reason is that it allows respondents a sufficiently wide choice to differentiate the scores, and yet not overly burdensome in their decisions (such as would be the case in more than seven-point scales. The second questionnaire was also administered among experienced professionals to explore the reasons for low awareness of carbon emissions and mitigation strategies. This questionnaire consisted of three sections: Section 1 focused on the psychological-cognitive factors, Section 2 tested on the social factors, and Section 3 focused on political factors. The respondents were asked to indicate their agreement on a five-point Likert scale, in which 1 = "totally disagree" and 5 = "totally agree".

The first questionnaire was administered to a sample of 111 construction practitioners in the Sri Lankan construction industry and the second questionnaire was administered to a sample of 31 experienced professionals in the industry. The targeted respondents included Architects, Civil Engineers, Electrical Engineers, Quantity surveyors, Facilities Managers and Compliance Managers from both the public and the private sector. The questionnaire was sent to different organizations in Sri Lanka including the Construction Industry Development Authority [CIDA], Institute of Quantity Surveyors of Sri Lanka [IQSSL], Institute of Engineers Sri Lanka [IESL], and developers on the member list of CIDA. Snowball sampling method was used to increase the sample size of the survey [36]. Respondents were invited to distribute the questionnaire among other construction professionals in their professional circle.

4. Method of Analysis

The data collected through the questionnaires were analyzed using the Statistical Package for Social Sciences (SPSS Version 20) [37]. Non-parametric statistical tests [38]—the Cronbach's alpha, the Relative Importance Index [RII] and descriptive statistics—were employed given that the data involved were based on ordinal measurement scales. These non-parametric statistical tests are useful when the population distribution is not exactly known and the sample size is small and unequal [39]. Cronbach's alpha test was used to measure the reliability of data by examining the internal consistency of the adopted measurement scale Leontitsis and Pagge [40]. The 'mean score' is an ideal method to establish relative importance in terms of awareness of carbon emission in the construction industry. Whilst it is simple to understand without the complication of other probabilistic parameters, this type of descriptive statistic reflects the representative score for each sampled item, as long as the standard deviation is not excessive. In fact, this method has been commonly used in similar research studies [41–43]. Chan and Kumaraswamy [41] used the mean score to establish the relative importance in identifying reasons in delaying civil engineering projects in Hong Kong, while Chan, Chan [42] used the same approach to evaluate the benefits of partnering projects. Tripathi and Jha [43] also used non-parametric tests to analyze the organizational performance attributes of construction firms in India. Five-point scales were transformed to relative importance indices to determine the rank of factors. The mean and the standard deviation of each individual factor do not reveal the relationship between them, which makes it improper to assess the overall ranking. Hence, the numerical scores were transformed to relative importance indices so that the relative ranking of each factor can be determined.

The RII was obtained from using the following formula:

$$Relative\ Importance\ Index(RII) = \frac{\sum w}{A \times N}, (0 \leq index \leq 1) \quad (1)$$

where w = weighting given to each factor by the respondents ranging from 1 to 5, where 1 is very low and 5 is very high, A = highest weight (i.e., 5 in this scenario), and N = total number of respondents. Moreover, correlation analysis techniques were used to determine the correlations among factors relating to embodied carbon mitigation strategies. Spearman rank correlation coefficient and Kendall'sTau-b coefficient tests were adopted to determine the monotonic relationship between ordinal variables. These coefficients indicate the strength and degree of relationship between two variable sets, which denotes the correlation among them.

Profile of Respondents: Out of 125 questionnaires distributed, 111 professionals returned the completed questionnaires, with a response rate of 89%. Once the survey questionnaires were distributed to potential stakeholders, the research team contacted and reminded them, from time to time, to respond to the questionnaire. This helped the survey team to boost the number of responses to 111 in total, which is a very good response rate for an exploratory study of carbon emission. The respondents work experience in the construction industry ranges from less than 1 year to 5 and years above. Table 2 shows the composition of the respondents in terms of profession and Figure 2 illustrates their experience in years. The majority of the respondents (60.36%) had experience of 2 to 5 and around one-fourth (22%) of the respondents had more than five years of experience in the construction industry.

Table 2. Composition of the respondents.

Profession	No. of Respondents	Percentage
Architect	21	18.92%
Civil Engineer	35	31.53%
Manager Compliance	3	2.70%
Electrical Engineer	12	10.81%
Facilities Manager	16	14.41%
Quantity Surveyor	24	21.62%

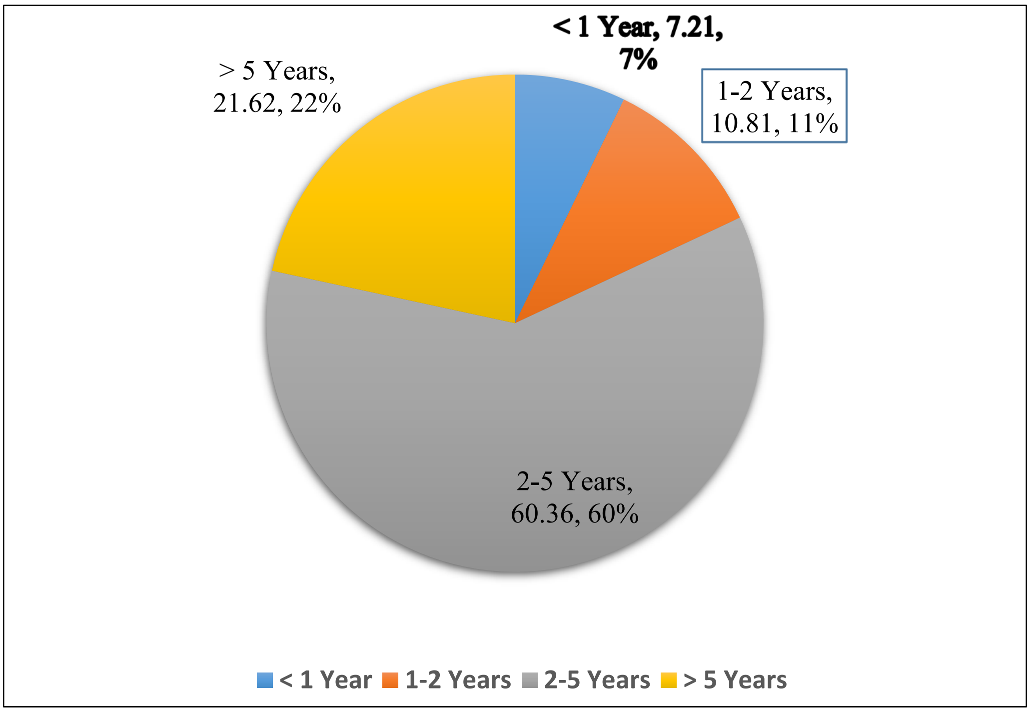

Figure 2. Experience of the respondents.

5. Empirical Analyses and Findings

5.1. Global Carbon Emissions

To assess the level of awareness and the knowledge on carbon emissions, the respondents were asked to rate their level of awareness and knowledge based on their experience and level of understanding on the subject. Prior to the analysis, a reliability test was performed. Among five different tests to test the reliability of data (Cronbach's alpha, Split half, Guttmann, Parallel, and Strict parallel [43], the Cronbach's alpha test, which is the most suitable test for these types of studies [44], was used in this study. This test is easier to use compared to other estimates as it only requires one test administration. Moreover, it adds validity and accuracy to the interpretation of data [45]. The purpose of this test is to measure and verify the internal consistency or reliability among the responses under the five-point Likert scale. Reliability is generally established if Cronbach's alpha is greater than 0.6 [46]. The value of 0.881 Cronbach's Alpha test statistic indicates that the five-point Likert scale adopted was consistent and reliable at the 5% significant level of the questionnaire survey.

As seen in Figure 3, the frequency analysis revealed that around 45% of the respondents were well-aware (high-awareness) of carbon emissions in general. However, their awareness about operational and embodied carbon emissions is relatively low. For example, only around 33% of respondents were well-aware of operational carbon emissions, whilst this figure for embodied carbon emission was only 19.8%. Similarly, Ibn-Mohammed et al. (2013) also mentioned that there is a lack of knowledge and awareness of embodied carbon emissions in the construction industry. The results also indicate that the respondents were little more aware of the operational carbon emissions than the embodied carbon emissions. Figure 4 further reaffirms the fact that the embodied carbon emission reduction still remains to be of low concern among Sri Lankan construction professionals. For example, almost half of the respondents (49.55%) seems to think that EC emission reduction is not that important, while a significant proportion of respondents (37.84%) also do not consider the reduction of OC emission is that important. This finding is however somewhat contradicted with the findings of Kumanayake, Luo [9]. They stated that the priority given to the operational carbon emissions in the past has now shifted more towards the embodied emissions, which is not yet the case with regard to the Sri Lankan construction industry. This clearly shows that the Sri Lankan construction professionals are still more concerned about the operational carbon emissions over embodied emissions.

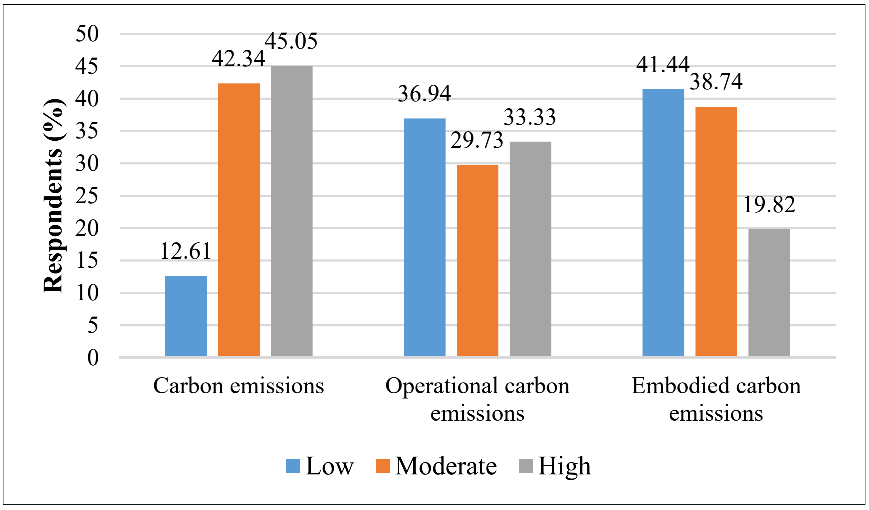

Figure 3. Awareness of global carbon emissions.

Overall, the results suggest that even though the knowledge and awareness about carbon emission are relatively low among Sri Lankan professionals, the majority of the respondents showed some knowledge in reducing OC emissions compared to EC emissions. This in line with Huang and Bohne [16], who stated that the global carbon reduction trend is still dominated by the OC emission reduction perspective.

To have a deeper understanding and cross-check their awareness regarding OC and EC emission in the construction industry, a set of statements relating to OC and EC emission were given (section II of the questionnaire) to indicate their level of agreement on them, which are seen in Table 3. Their responses were categorized into three groups: Respondent scores 2 or less were named "poor-awareness" category; scores 3 as "neutral" category; and scores 4 or more as "well-awareness" category.

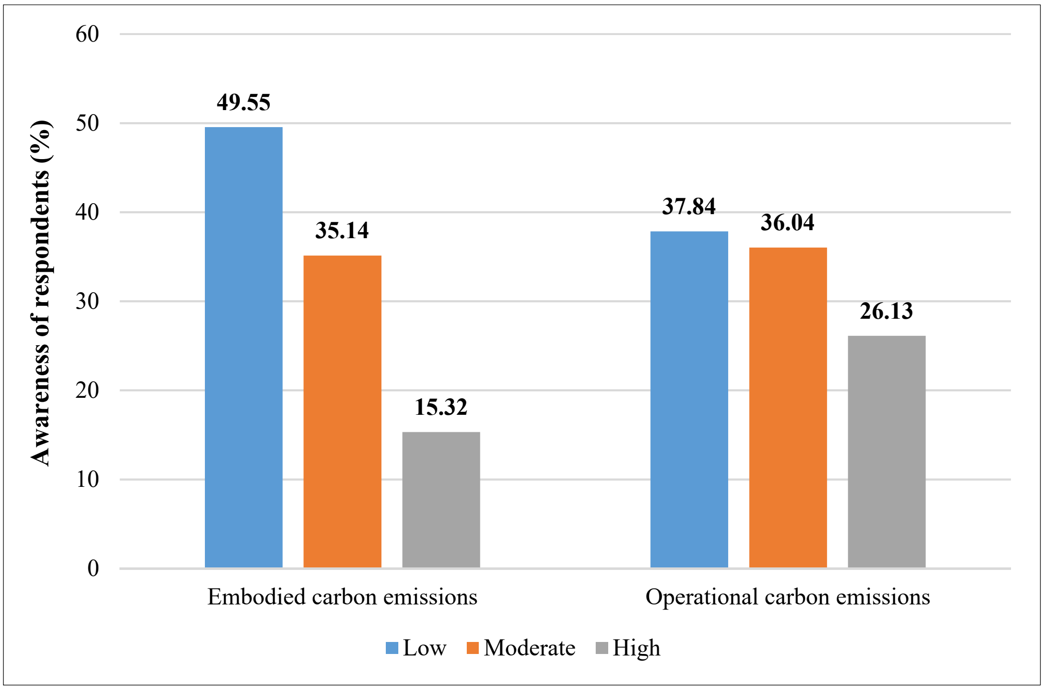

Figure 4. Perception of the importance of carbon emission reduction.

Table 3. Level of awareness of carbon emission in the construction industry.

Factors	Percentage of Respondents Scoring		
	Disagree (Low-Awareness)	Neutral (Moderate Awareness)	Agree (Well-Awareness)
Good awareness of global carbon emission levels and how they occur	44.14	36.04	19.82
Good awareness of impacts caused by the construction industry towards total global carbon emissions	32.43	41.44	26.13
Well aware of the two emission types; embodied carbon emissions and operational carbon emissions	56.76	24.32	18.92
More concerned about the operational carbon emissions than the embodied carbon emissions	44.14	36.94	18.92
Sound knowledge on embodied carbon mitigation strategies	75.68	10.81	13.51
Personal responsibility to ensure that the construction process has a low impact on the environment in terms of carbon emissions	39.64	36.94	23.42
Consider reduction in embodied carbon emission as a personal responsibility in the construction project	51.35	23.42	25.23

The poor awareness about carbon emission is again clearly demonstrated with the results reported in Table 3. Among the three 'awareness' categories, 'low-awareness' category has received the largest percentage scores, reflecting an overall poor knowledge or awareness of carbon emission. Under the 'low awareness', "sound knowledge on embodied carbon mitigation strategies", "well aware of embodied carbon emissions and operational carbon emissions" and "consider reduction in embodied carbon emission as a personal responsibility" have received larger percentage scores of 75.68%, 56.76%, and 51.35%, respectively. This indicates not only that respondents are not very well aware of the carbon emission issue, but they also do not consider carbon reduction is their responsibility. Likewise, a considerable portion of higher percentage scores (responses) come under the 'moderate awareness' category, reflecting little knowledge and awareness on the global carbon emission impact of the construction industry.

Based on the respondents' feedback on the Likert scale, the mean and the standard deviation of the above statements were analyzed further. The results revealed that respondents had the least awareness about the carbon emission mitigation strategies which was ranked at the bottom. It was further evidence that the respondents had a better awareness about the impacts of the construction industry towards total global carbon emissions as it was ranked highest. This was an encouraging result which indicates that construction practitioners in Sri Lanka are in the right track to reduce negative environmental impacts of construction. A significant fact to note in Table 4 is that all the statements which were related to embodied carbon emission were ranked at the bottom which indicates that respondents awareness on embodied carbon emissions were relatively low compared to other facts on global carbon emissions.

Table 4. Mean and ranking derivation on statements related to carbon emissions.

Factors	Descriptive Statistics		
	Mean	Standard Deviation	Rank
Good awareness of global carbon emission levels and how they occur	2.75	0.847	3
Good awareness of impacts caused by the construction industry towards total global carbon emissions	2.93	0.850	1
Well aware of the two emission types; embodied carbon emissions and operational carbon emissions	2.56	0.931	6
More concerned about the operational carbon emissions than the embodied carbon emissions	2.61	0.946	5
Sound knowledge on embodied carbon mitigation strategies	2.17	0.971	7
Personal responsibility to ensure that the construction process has a low impact on the environment in terms of carbon emissions	2.80	1.069	2
Consider reduction in embodied carbon emission as a personal responsibility in the construction project	2.70	1.005	4

Kumanayake et al. (2018) stated that Sri Lankan building sector has identified the requirement to mitigate carbon emissions. The results of the present study, however, indicate a lack of awareness and focus on carbon mitigation, especially embodied carbon emission mitigation. These results also reflect stakeholders' personal responsibility. They do not seem to consider the reduction of carbon emission as their responsibility. This may be partly due to their poor understanding and knowledge about the seriousness of construction-related carbon emissions. As mentioned in the literature review section, scarcity of research studies on Sri Lankan construction related carbon emissions might be another major reason for this poor awareness and understanding. As global researchers have started to focus more on reducing embodied carbon emissions, several embodied carbon mitigation strategies have been identified. According to the above findings, it is evident that Sri Lankan construction professionals are lagging behind in identifying the importance of embodied carbon emission reduction. Therefore, this study was then focused on identifying the awareness of the selected respondents on embodied carbon mitigation strategies.

5.2. Embodied Carbon Mitigation Strategies

The respondents were asked to rate 17 embodied carbon mitigation strategies, identified through the literature review, according to their awareness of each strategy. The responses were again categorized as 'low' (rating 2 or less), 'moderate' (rating 3), and 'high' (rating 4 or more). The results are reported in Table 5.

Table 5. Level of awareness on embodied carbon mitigation strategies.

Factors	Percentage of Respondents Scoring		
	Low (≤ 2)	**Moderate (3)**	**High (≥ 4)**
Practical guidelines for the wider use of low-EC materials	52.25	15.32	32.43
Better design	6.31	36.94	56.76
Re-use and recovery of EE/EC intensive construction materials	26.13	44.14	29.73
Tools, methods, and methodologies	32.43	42.34	25.23
Policy and regulations (Governments)	20.72	49.55	29.73
Refurbishment of existing buildings instead of new built	10.81	45.95	43.24
De-carbonization of energy supply/grid	48.65	25.23	26.13
Inclusion of waste, by-product, used materials into building materials	40.54	30.63	28.83
Increased use of local materials	11.71	40.54	47.75
Policy and regulations (Construction sector)	26.13	36.04	37.84
People-driven change (key role of all BE stakeholders)	37.84	37.84	24.32
More efficient construction processes/techniques	22.52	45.95	31.53
Carbon mitigation offsets, emissions trading, and carbon tax	38.74	18.02	43.24
Carbon sequestration	57.66	20.72	21.62
Extending the building's life	12.61	43.24	44.14
Increased use of prefabricated elements/off-site manufacturing	27.93	35.14	36.94
Demolition and rebuild	18.92	46.85	34.23

Out of 17 strategies, respondents were well aware of 'better design' and 'increased use of local materials' as strategies to combat carbon emission. They also had a relatively better understanding and awareness about the importance of extending the building's life, refurbishment of existing buildings instead of new built, and carbon mitigation offsets, emissions trading, and carbon tax as strategies to mitigate carbon emissions. Results also revealed that a significant portion of respondents have reasonably good awareness (moderate awareness) about the importance of policy and regulations, efficient construction processes/techniques, demolition and rebuild, and re-use of EE/EC intensive construction materials in achieving the goal of low carbon goal. However, respondents were less knowledgeable about the significance of carbon sequestration, guidelines for wider use of low-EC materials, de-carbonization of energy supply/grid, and the use of waste, by-products, used materials in the construction process. These strategies are mainly related to advanced technology related emission strategies.

This is further confirmed through the results tabulated in Table 6, in which respondents were asked to rank mitigation strategies, according to their awareness and importance. Overall, the results reported in Tables 5 and 6 reflect an important point: Sri Lankan construction professionals are basically aware of basic and conventional carbon mitigation strategies such as better design (low-carbon design), extension of building life and refurbishment of existing buildings and carbon tax, but their awareness of recently established micro-level strategies is relatively poor.

According to the respondents, better design, more efficient construction processes and increased use of local materials were indicated as the most important carbon mitigation strategies. Refurbishment of existing buildings instead of new built, demolition and rebuild and inclusion of waste, by-product, used materials into building materials followed as some of the other most useful embodied carbon mitigation strategies. The least important/useful strategy according to the respondents was carbon sequestration. This was followed by practical guidelines for wider use of low EC materials and de-carbonization of the energy supply grid. This is in line with the findings in Table 5. The strategies, which were ranked least importance, were also ranked as the strategies with the lowest awareness.

In order to understand the extent to which the awareness on embodied carbon mitigation strategies relates to the importance of mitigation strategies, correlation tests were undertaken. The Spearman rank correlation test was conducted among respondent's awareness and how they ranked the mitigation strategies based on importance.

Table 6. Ranking of perception: the importance of embodied carbon mitigation strategies.

Strategy	RII	Rank
Better design	0.75	1
More efficient construction processes/techniques	0.75	2
Increased use of local materials	0.75	3
Refurbishment of existing buildings instead of new built	0.73	4
Demolition and rebuild	0.73	5
Inclusion of waste, by-product, used materials into building materials	0.72	6
People-driven change (key role of all BE stakeholders)	0.72	7
Increased use of prefabricated elements/off-site manufacturing	0.71	8
Policy and regulations (Governments)]	0.70	9
Carbon mitigation offsets, emissions trading, and carbon tax	0.70	9
Tools, methods, and methodologies	0.70	11
Policy and regulations (Construction sector)	0.70	12
Extending the building's life	0.70	13
Re-use and recovery of EE/EC intensive construction materials	0.68	14
De-carbonization of energy supply/grid	0.66	15
Practical guidelines for wider use of low-EC materials	0.65	16
Carbon sequestration	0.57	17

According to Table 7, all the strategies indicated a positive coefficient with large strength and except for refurbishment of existing buildings instead of new built, Carbon sequestration and Extending the building's life, the Sig. 2 tailed correlation was also applicable to the embodied carbon mitigation strategies. This clearly entails the fact that lack of awareness about embodied carbon emission mitigation strategies results in not recognizing the importance of those strategies. This further suggests that proper awareness of embodied carbon mitigation strategies may result in a better understanding of their importance, which will ultimately result in better adoption of the strategies. Since it is evident that there is a significant issue of lack of awareness, this study then focused on identifying the reasons for this issue.

5.3. Reasons for Low-awareness

If we are to increase the awareness of the importance of carbon emission as well as carbon mitigation strategies in the construction industry, we need to understand the reasons for low-awareness among construction professionals. Accordingly, an expert survey with 31 experienced construction professionals was conducted and the profile of the respondents participated in the survey are illustrated in Figure 5. More than 95% of the respondents in the survey had 10 years or above experience in the construction industry.

As seen in Table 8, reasons for low awareness were categorized under three main categories: psychological-cognitive, social and political. The majority of the respondents believed that actions to reduce carbon footprint will demand much of their time, money and effort and thus no incentives to initiate such measures. Moreover, they perceived that measures to reduce carbon emission should be initiated and handled by the government and other authorities. Construction professionals also believe that the government and other relevant authorities have the necessary power and the resources to address this issue of carbon emission in the construction industry. It is thus evident that the majority of professionals perceive addressing an important issue like carbon emission is a political decision rather than a particular profession decision. This mentality of professionals may have been a major reason for the poor knowledge/awareness about the importance of carbon emission and mitigation strategies among construction stakeholders/ professionals.

Table 7. Correlation among awareness and importance of embodied carbon emissions.

Factors	Correlation Analysis			
	Spearman Rank Correlation	Spearman Sig. (2 Tailed)	Kendall's Correlation Coefficient	Kendall's Sig, (2 Tailed)
Practical guidelines for the wider use of low-EC materials	0.258	0.006	0.238	0.004
Better design	0.242	0.011	0.206	0.015
Re-use and recovery of EE/EC intensive construction materials	0.233	0.014	0.202	0.014
Tools, methods, and methodologies	0.113	0.236	0.079	0.338
Policy and regulations (Governments)	0.228	0.016	0.179	0.027
Refurbishment of existing buildings instead of new built	0.348	0.000	0.287	0.001
De-carbonization of energy supply/grid	0.199	0.036	0.166	0.039
Inclusion of waste, by-product, used materials into building materials	0.276	0.003	0.185	0.024
Increased use of local materials	0.203	0.033	0.108	0.202
Policy and regulations (Construction sector)	0.353	0.000	0.245	0.002
People-driven change (key role of all BE stakeholders)	0.235	0.013	0.138	0.086
More efficient construction processes/techniques	0.218	0.022	0.092	0.271
Carbon mitigation offsets, emissions trading, and carbon tax	0.325	0.001	0.247	0.002
Carbon sequestration	0.421	0.000	0.379	0.000
Extending the building's life	0.373	0.000	0.256	0.002
Increased use of prefabricated elements/off-site manufacturing	0.150	0.117	0.098	0.237
Demolition and rebuild	0.153	0.109	0.168	0.049

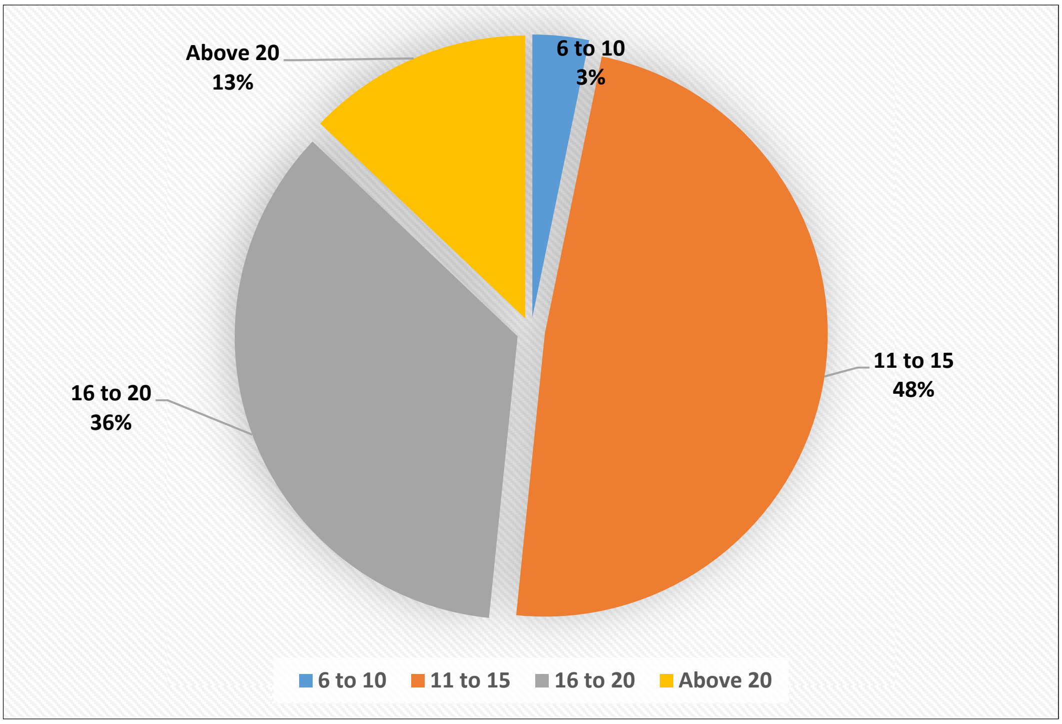

Figure 5. Profile of respondents.

Table 8. Reasons for poor awareness of carbon emissions and mitigation strategies.

	Percentage of Agreed Responses
Psychological-Cognitive Reasons	
The outcome of carbon footprint will not happen in my lifetime	64.52
There are more important issues than the reduction of carbon footprint	64.51
Nothing I can do to reduce carbon footprint, it is too complex to handle	61.29
Social Reasons	
If I take some initiatives to reduce carbon footprint, society will brand me as an activist or radical	67.74
Actions to reduce carbon footprint will demand much of my time, money and effort	96.78
Political Reasons	
Handling carbon emission/footprint is a political matter	67.74
The government and other authorities can handle this issue on their own	83.87
This is not my problem, it is the responsibility of government and other authorities, so let them handle it	90.32

6. Discussion

The building sector has been recognized as a major GHG emitter globally. The construction professionals and other stakeholders are in search of methods and measures to mitigate the adverse impact of the construction industry on the environment. Many stakeholders believe that proper awareness and knowledge about the importance of carbon emission reduction is a key to achieve the GHG emission reduction goals. This study, which is based on a questionnaire survey followed by an expert survey, investigated the awareness and knowledge of the Sri Lankan construction professionals about carbon emissions in general and embodied carbon (EC) emission and carbon mitigation strategies in particular. The survey results suggest that the Sri Lankan construction professionals have poor awareness about carbon emissions, especially about EC emission and EC mitigation strategies. The results indicate an important point: Sri Lankan construction professionals are basically aware of some basic and conventional carbon mitigation strategies such as better design (low-carbon design), an extension of building life and refurbishment of existing buildings and carbon tax, but their awareness of recently identified advanced micro level technological strategies is relatively poor. Kumanayake et al. [9] stated that Sri Lanka has already recognized the need to address carbon mitigation in buildings and are in the process of implementing measures to assess the current performance. However, survey results indicated otherwise as majority of the respondents lacked awareness on carbon emissions as well as the EC mitigation strategies. It is argued that construction and other professionals are more concerned about the operational carbon emissions [47], which might be a reason for the survey results of this study.

Furthermore, it was revealed that lack of awareness of construction professionals on embodied carbon mitigation strategies has resulted in considering the embodied carbon mitigation strategies to be of lesser importance. Correlation analysis indicated a positive relationship between lack of awareness and importance. Therefore, it is evident that necessary actions are required to improve the awareness of Sri Lankan construction professionals on embodied carbon mitigation strategies. As the construction professionals are focusing heavily on reducing operational carbon emissions, which was revealed through the literature as well as the survey results, embodied carbon emissions are likely to increase significantly. As indicated by Crawford [7], EC emissions have become a significant contributor to the global carbon emissions which could increase up to 50% of the whole life impacts of the buildings. Ibn-Mohammed et. al [48] indicated that EC emissions would increase even up to 70% in UK if EC emission reduction is not addressed properly. Therefore, immediate actions are required to be implemented to enhance the awareness on embodied carbon mitigation strategies that will enable the construction professionals to implement them in construction projects. Apart from the actions that can be implemented at the micro level, macro level actions such as establishing government policies incorporating the embodied carbon mitigation strategies need to be developed to successfully achieve the goal of net zero carbon construction.

Survey analysis clearly revealed the lack of awareness about carbon emissions among the Sri Lankan construction professionals has resulted in low or no adaption of carbon mitigation strategies, especially embodied carbon emissions. This study therefore explored the reasons for low awareness which were analyzed under three main categories: psychological-cognitive, social and political. The majority of the respondents believed that actions to reduce carbon footprint should be initiated and handled by the government and other authorities. They also believe that the government and other relevant authorities have the necessary power and the resources to address this important issue of carbon emission. It is thus evident that the majority of professionals perceive that addressing the carbon emission issue is a political decision rather than a particular profession decision. Apart from the reasons mentioned above, another major cause for this lack of awareness is the unavailability of comprehensive research studies on EC emissions and EC mitigation strategies in Sri Lanka and other developing countries. Body of literature on this domain is much higher in the developed countries compared to the developing countries which has been further confirmed by the studies conducted by Kofoworola and Gheewala [22], Ramesh et al. [23], Varun et al. [24], Paulsen and Sposto [25], Pinky Devi and Palaniappan [26], and Wen et al. [27]. Therefore, it is necessary to conduct comprehensive research studies to identify the impacts of EC emissions in the developing countries and thereby develop EC mitigation strategies.

7. Conclusions

As there is still no clear consensus among stakeholders on how to address the EC mitigation issue around the world, this study would not only provide the necessary impetus to drive the momentum on how to address this global issue, but it also enriches the limited body of literature. The main insight drawn from the findings is that, as the majority of the construction professionals opined that carbon mitigation strategies are a political goal, closer cooperation and collaboration between the government and the construction industry should be a step forward to achieve the goal of carbon reduction. Findings clearly indicate the necessity of enhancing the awareness and knowledge on embodied carbon mitigation strategies among the Sri Lankan construction professionals. The authors believe that the finding is a clear reflection of the current situation in many developing countries with regard to carbon emission and mitigation strategies.

This is exploratory research and its recommendations should be generalized with caution due to a few limitations, including its cultural and geographical limitations. As identified through the literature review, there is a major scarcity in research related to carbon emissions in developing countries such as Sri Lanka. Therefore, it is necessary to conduct more research studies to explore the carbon emissions of construction industry in the Sri Lankan context as well as in other developing countries as they contribute significantly to the global carbon emissions. Moreover, this study revealed that construction professionals lack awareness about embodied carbon mitigation strategies. Thus, studies to explore methods to increase awareness among construction professionals on embodied carbon mitigation strategies would be timely. Future work in the area can be enhanced with increased sample size. It could also be interesting to look into the barriers to implement embodied carbon mitigation strategies in the Sri Lankan construction industry. The effectiveness of adopting carbon mitigation strategies in the Sri Lankan construction projects can also be evaluated. A study on identifying cost trade-off of adopting the embodied carbon mitigation strategies to the construction projects in Sri Lanka is also timely.

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