Yahanpath, R., Wijekoon, W.M.C.L.K. and Kumarathunga, J., 2024. Exploratory study on adAptability of wall-mounted solar panels for high-rise buildings in Sri Lanka. In: Sandanayake, Y.G., Waidyasekara, K.G.A.S., Ranadewa, K.A.T.O. and Chandanie, H. (eds). *Proceedings of the 12th World Construction Symposium*, 9-10 August 2024, Sri Lanka. pp. 458-469. DOI: https://doi.org/10.31705/WCS.2024.36. Available from: https://ciobwcs.com/papers/

EXPLORATORY STUDY ON ADAPTABILITY OF WALL-MOUNTED SOLAR PANELS FOR HIGH-RISE BUILDINGS IN SRI LANKA

Ravindu Yahanpath[1], W.M.C.L.K. Wijekoon[2], and Janani Uvasara Kumarathunga[3]

ABSTRACT

The global energy crisis and the unsustainable resource consumption patterns of the construction industry has driven a growing interest in sustainable practices. The integration of renewable energy sources, such as solar energy, has emerged as a key strategy to achieve sustainability goals. While various applications of solar systems exist, wall-mounted solar panels have not been widely utilised in Sri Lanka, and no prior research has been conducted on this topic in the country. This study acts as an exploratory study which aims to investigate the feasibility and adaptability of implementing wall-mounted solar panels in high-rise buildings in Sri Lanka. Data was gathered through a comprehensive literature review and semi-structured interviews with experts on solar energy and construction practices. The study found several barriers towards the implementation of wall-mounted solar panels in Sri Lanka. Notably, the effectiveness of the wall-mounted solar panel system was found to be hindered by the path of the sun in Sri Lanka. The absence of proper regulations or Sri Lanka Standards (SLS) specific to wall-mounted solar panels presented an additional challenge. Despite the barriers identified, expert interviews revealed potential strategies to overcome these challenges. The findings of this research study contribute to the understanding of the feasibility of implementing wall-mounted solar panels in high-rise buildings in Sri Lanka, shedding light on the unique context and factors influencing their adoption. This study underscores the importance of considering local factors and developing appropriate regulations to promote sustainable energy practices in the construction industry.

Keywords: *Adaptability; High-Rise Buildings; Wall-Mounted Solar Panels.*

1. INTRODUCTION

The concern for sustainable development has increased among the global community in the face of unprecedented population growth and significant industrial and technological advancements. As a major economic sector, the construction industry is compelled to contribute to these sustainability objectives. Hence, there has been much discourse on feasible sustainability and improving the environmental impact of construction activities.

---

[1] Junior Quantity Surveyor, QS Practice (Pvt) Ltd, Sri Lanka, ravinduyahanpath2000@gmail.com
[2] Senior Lecturer, Department of Quantity Surveying, Sri Lanka Institute of Information Technology, Sri Lanka, kumari.l@sliit.lk
[3] Quantity Surveyor, Nawaloka Constructions Company (Pvt) Ltd, Sri Lanka, janauvasara@gmail.com

The construction industry is directly responsible for over one-third of global energy consumption and 39% of the total direct carbon emissions (Min et al., 2022) However, renewable energy systems have the potential to mitigate the risk of disruptions in the energy supply and decrease dependency on foreign fuels (Jakštas, 2020). Furthermore, by reducing the production of greenhouse gases, renewable energy-based technologies can provide a great opportunity to decrease global warming (Baidya & Nandi, 2020). The most powerful source of energy known to us is the Sun (Şenpinar, 2018). By utilising the sun's energy (which is renewable, clean and reliable) in place of unsustainable energy sources, numerous environmental, economic and social benefits can be achieved (Letcher, 2022). Electricity generation through solar panels is a green technique that has gained popularity in the past decade owing to its environmental benefits (Allouhi et al., 2015). There are many variations of solar panel applications ranging from the most used rooftop solar panels, to specialised systems such as solar-powered road lighting systems, solar ponds etc. (Smith et al., 2022). However, one major constraint associated with the use of solar energy is the task of allocating space for the panels. In cities where commercial high-rise buildings have limited roof area and ground area, the task of reserving space for solar panels is often tedious and costly, thus discouraging potential clients. A promising alternative is the application of wall-mounted solar panels, which have shown potential for achieving the desired results while utilising the often-unused wall area in high-rise buildings. However, its adaptability within the built environment of Sri Lanka remains unexplored. Furthermore, there is a notable lack of research focusing on the adaptability of the wall-mounted solar panels in high-rise buildings. Therefore, this study aims to bridge these gaps by investigating the adaptability of wall-mounted solar panel design concept in high-rise buildings in Sri Lanka. The objectives set to achieve this aim were: (i) Review the concept of wall-mounted solar panel design, its importance and its availability in Sri Lanka, (ii) Investigate the suitability and the associated barriers to adopting wall-mounted solar panels in high-rise buildings in Sri Lanka, and (iii) Propose strategies to overcome the identified barriers.

2. LITERATURE REVIEW

2.1 SOLAR ENERGY FOR SUSTAINABLE CONSTRUCTION

The construction industry plays a significant role in regulating the trajectory of a country's growth, often acting as a determinant of the country's technological, infrastructural, social and economic development (Hussain et al., 2022). Consequently, the built environment accounts for over 40% of the energy consumed across the globe (Devi & Palaniappan, 2017). Unfortunately, the energy wastage associated with these functions has a substantial negative impact on the environment. Therefore, it is imperative for both the industry and the individual structures to prioritise sustainable energy solutions (Dräger & Letmathe, 2022). As the predominant renewable energy source, solar energy boasts the characteristics of being clean, inexhaustible, renewable, and widely spread compared to other energy sources (Peng et al., 2020). Yan et al. (2019) found that solar energy systems now can generate electricity at costs equal or to lower than local grid-supplied electricity.

2.2 SOLAR CELL FUNCTIONALITY AND ELECTRICITY GENERATION

Solar cells are semiconductor devices that can convert sunlight into electricity through the photovoltaic effect. An assembly of interconnected solar cells is known as a "Solar

Module" (Sharma & Kothari, 2017). The energy conversion process includes the absorption of protons which produces electron-hole pairs in the semiconductor, and charge carrier separation through a P-N junction (Soga, 2006). Primarily, solar cells are made up of semiconductor material (such as Silicon) which absorbs the photons emitted through sun rays (Bhatia, 2014). A typical solar cell comprises two layers of semiconductors (P and N), with the junction between them acting as a diode which allows electrons to move from N to P (Mellit & Kalogirou, 2022). This movement is created when photons with sufficient energy hit the solar cell, causing excess electrons in the N-layer and an electron deficiency in the P-layer, thus creating extra spaces known as "holes" (Mellit & Kalogirou, 2022; Asdrubali & Desideri, 2019). Then, the negatively charged electrons flow from the N-layer to the holes in the P-layer, causing a free flow of electrons which generates electricity (Mellit & Kalogirou, 2022; Asdrubali & Desideri, 2019; Hussain, 2018). The generated electricity is then converted from DC to AC using an inverter to be used locally or fed to the main electrical grid (Khare et al., 2023).

2.3 WALL-MOUNTED SOLAR PANELS FOR HIGH-RISE BUILDINGS

Urban areas are experiencing an increase in high-rise building construction due to the impending shortage of land (Sharma & Kothari, 2017). While roof-top panels are the most common application of solar panels, the potentials of this application are restricted due to the limited roof area of high-rise buildings in urban areas (Zhou et al., 2019). Hence, roof-top solar panels may not be sufficient to fulfil the energy requirements. However, the wall area in high-rise buildings is significantly greater than the roof area and thus, as suggested by Nguyen et al. (2019), can be utilised as an alternative by installing a large number of solar panels on the vertical walls. Saadatian et al. (2013) noted that wall-mounted solar panels are an ideal option considering the long-term goal to improve sustainability within the construction industry through renewable energy sources. Sharma and Kothari (2017) identified two prominent types of building façade systems that are suitable for wall-mounted solar panels: Rainscreen cladding and curtain walling systems. Rain screen cladding systems consist of a stainless-steel sub-frame fitted with cladding panels and fixing brackets which are bolted onto the internal walls of the building (Pérez et al., 2012). Curtain walls use lightweight Aluminium or Stainless-Steel frames and are fitted with transparent or opaque solar panels (Sharma & Kothari, 2017). They are airtight and can resist wind and weather (Kurian & Karthi, 2021; Roberts & Guariento, 2009).

2.4 BENEFITS OF WALL-MOUNTED SOLAR PANELS FOR HIGH-RISE BUILDINGS

Traditionally, solar panels are mounted on horizontal surfaces at high elevations, most commonly on rooftops or slightly inclined surfaces which are exposed to direct sunlight (Osigbemeh et al., 2022). This system allows the panels to harness solar energy to the max. However, on account of practical difficulties such as restricted access to rooftops and space limitations, wall-mounted solar panels are being proposed as alternatives (Kiboi & Moses, 2022). Many unique benefits that are associated with wall-mounted solar panels. Primarily, using wall-mounted solar panels allows the rooftop space to be saved. Since the rooftop space in high-rise buildings is limited due to reasons such installation of HVAC systems, infrastructure maintenance systems, communication equipment etc., wall-mounted solar panels are a convenient option to generate renewable energy without compromising rooftop space (Osigbemeh et al., 2022). In high-rise buildings, the wall area that is exposed to sunlight is greater than the roof area. Therefore, wall-mounted solar panels can generate more electricity than rooftop solar panels (Salama, 2018). Another advantage is the ease of installation and maintenance of wall-mounted solar panels compared to rooftop solar panels. Wall-mounted solar panels can be designed and installed so that the high wind load applied in high-rise buildings can be withstood (Kiboi & Moses, 2022).

3. METHODOLOGY

This study was initiated with an outlook on the significance of solar energy and solar energy generation mechanisms. This was cemented by a survey of past literature leading to insights on the benefits of wall-mounted solar panels for high-rise buildings. Journal articles, conference proceedings, newspaper articles, and reports relating to solar energy and the benefits of wall-mounted solar panels were gathered and scrutinised to perform the literature review. The study follows a qualitative research approach, allowing for an in-depth understanding of the factors affecting the adaptability of wall-mounted solar for Sri Lankan high-rise buildings. Considering the novelty of the subject in the context of Sri Lanka, it was decided that a qualitative approach is more suitable for the study. The data for this study was collected through semi-structured interviews with qualified construction professionals with experience in solar installations. This research strategy was chosen as it would allow for a large amount of required data to be gathered with flexibility. According to Fellows and Liu (2015), semi-structured interviews offer a combination of the greatest qualities of structured and unstructured interview formats, allowing for greater freedom in the questions and more clarity in the responses. This study utilises an interpretivism research paradigm, where the interviewees' answers are based on their present experiences, knowledge, and comprehension of solar energy adaptability. Purposive sampling was applied in choosing interviewees. This method enables the selection of respondents that are most suited to the research topic and therefore, ensures that all respondents are well-versed regarding construction, solar energy applications and the adoptability of wall-mounted panels (Saunders et al., 2019). Among the respondents, R10 had the most knowledge regarding the study topic, as a solar energy specialist. R2 and R9 had worked with reputed solar-power suppliers for over two years in their careers. R3, R4, R6, R7 and R8 knew regarding solar energy and solar panel installation through project work experience. R1 and R5, who had the least years of work experience, had worked in projects which utilised solar power and therefore, had sufficient exposure to the subject. The profiles of the chosen respondents (Nr =10) have been illustrated in Table 1.

Table 1: Semi-structured interview respondent profile

Code	Profession	Years of Experience			
		Below 10	10-20	21-30	Over 30
R1	Architect	✓			
R2	Architect		✓		
R3	MEP Engineer		✓		
R4	MEP Engineer			✓	
R5	Quantity Surveyor	✓			
R6	Quantity Surveyor			✓	

Code	Profession	Years of Experience			
		Below 10	10-20	21-30	Over 30
R7	Civil Engineer		✓		
R8	Civil Engineer				✓
R9	Project Manager				✓
R10	Solar energy specialist				✓

The qualitative data was structured and summarised using manual content analysis. Manual content analysis was preferred over software-based analysis because it allowed the information to be contextualised better, thus capturing the opinions and other subjective elements of the interview findings.

4. ANALYSIS

4.1 AVAILABILITY OF WALL-MOUNTED SOLAR PANELS IN SRI LANKA

Considering the broad range of disciplines from which the respondents hailed, the authors were able to gather a wide variety of knowledge. The semi-structured interviews commenced with a set of questions which gathered demographic data and primary data of the interviewees. In the beginning, all interviewees identified solar energy as a good source of renewable energy, unanimously agreeing on its renewable and unlimited nature. The interviewees were inquired regarding the availability of wall-mounted solar panels in Sri Lanka. Out of the ten respondents, nine (Nr=9) stated that this concept is not available in Sri Lanka yet, while one respondent (Nr=1) R2, stated that there is a possibility that the concept may have been introduced to Sri Lanka already. However, R10 confirmed that the Sri Lanka Sustainable Energy Authority (SLSEA) has not permitted the installation of wall-mounted solar panels in Sri Lanka yet.

4.2 SUITABILITY OF WALL-MOUNTED SOLAR PANELS FOR HIGH-RISE BUILDINGS IN SRI LANKA

Among the ten respondents, nine (Nr=9) stated that there are advantages of wall-mounted solar panels that make them suitable for Sri Lanka. R5 and R8 expressed concerns regarding the cost implications. R10 pointed out that because the main point of concern for the clients is the cost, the feasibility highly depends on the cost difference between wall-mounted solar panels and rooftop solar panels. R5 stated that considering the novelty of the concept in Sri Lanka, finding suitable contractors, experts and consultants would be difficult, and thus costly. On the other hand, R2 and R10 believed that this concept would be ideal for high-rise buildings. The walls of high-rise buildings can accommodate a bulk area, particularly in a country such as Sri Lanka which is primarily sunny for most of the year. For these reasons, R2 and R10 maintained that wall-mounted panels could generate a large amount of electricity. However, R9 held the view that the disadvantages of this concept outweigh the advantages and that the effectiveness is far lesser compared to rooftop solar panels. R9 argues that considering the lower efficiency, the adoption of wall-mounted panels will not be feasible, especially when a more suitable option is already in use.

4.3 BARRIERS TOWARDS ADOPTING WALL-MOUNTED SOLAR PANELS INTO HIGH-RISE BUILDINGS IN SRI LANKA

A critical barrier towards adopting wall-mounted solar panels is the lack of a regulated procedure in Sri Lanka to implement the concept. R10 elaborated that at present, only rooftop, ground-mounted and floating solar applications are in use in Sri Lanka. Sri Lanka Sustainable Energy Authority (SLSEA) is the regulatory body of Sri Lanka responsible for the implementation, regulation and monitoring of sustainable energy applications. The authors further verified this by contacting the SLSEA, which revealed that there is no legal framework available to approve wall-mounted solar applications for Sri Lanka. Further, the SLS quality certificates only exist for the above-mentioned solar applications. The trajectory of the sun is another barrier towards the implementation of wall-mounted solar in Sri Lanka. Sri Lanka is closer to the equator compared to European countries. Therefore, the sun passes directly above the country, whereas in the West, the trajectory is slightly tilted, making it ideal to utilise wall-mounted solar panels. R10 stated that several pilot tests conducted by their organisation have revealed the negative impact caused by the sun's trajectory.

A major barrier that most respondents recognised is the initial investment compared with the effectiveness of wall-mounted solar panels. R1, R3, R5, R6, R7, R9 and R10 expressed concerns regarding the capital investment recovery period. To quote R10, "*Wall-mounted solar panels may have its advantages, but when compared to roof-top solar, it takes a longer time to generate the same number of units. This ultimately means that it is harder to recover the initial investment*". Compared to rooftop solar panels, wall-mounted solar panels receive less time of sunlight. According to R9 and R10, the peak hours for typical solar panels to generate electricity are 10 am to 2 pm. However, according to R3 and R4, when compared with rooftop solar panels, the effectiveness of wall-mounted solar panels is around 50% less. Therefore, the quantity of electricity units produced is relatively less. Ultimately, the time taken to recover the initial investment increases. R7 stated that the investment recovery period has increased by about 80% compared to rooftop solar panels. R1 and R4 both noted that to accurately calculate the effectiveness and investment recovery period, a comprehensive quantitative study should be done on a case study basis. According to R4, "*This is a concept that must be explored further. We must not dismiss the advantages of wall-mounted solar due to the setbacks. But, to get the most accurate data, in-depth studies must be done to get the actual number*". Furthermore, R9 noted that "*To get the most out of the advantages of wall-mounted solar, we can use it in conjunction with roof-mounted solar*".

R1, R2, R3, and R4 expressed concern over the reflection of the sunlight falling on the wall-mounted solar panels. In the rooftop solar application, the reflected sunlight is not a major concern because it is directed back towards the sky. However, as stated by the interviewees, wall-mounted solar panels are more likely to reflect the sunlight horizontally, thus shining onto nearby buildings and interfering with their operations. To compound matters, this reflection can be a hindrance to nearby vehicle drivers, threatening to block their vision and cause accidents. The respondents concluded that unless mechanisms were implemented to redirect or block the reflected sunlight, the adaptability of wall-mounted panels would be greatly reduced due to this barrier. R4, who is an MEP engineer, noted that "*There have been suggestions made to the CEB about fixing solar panels along the expressway, to utilise the unused space. However, a major* *concern that arose was whether the panels would be a hindrance to drivers due to the reflection of sunlight*"

All respondents except R1 and R2 agreed that wall-mounted solar panels could increase the aesthetic appearance of the building. However, it is noteworthy that both R1 and R2 are experienced architects. They argue that due to the limited flexibility of the appearance of wall-mounted panels, it would give the buildings a monotonous and unappealing look. According to R1 and R2, the perspective of architects in general regarding the appearance of wall-mounted solar panels is negative due to the aforementioned reasons. This barrier is graver than it may be perceived because the best means of raising client awareness regarding wall-mounted solar panels is through the architect. If architects hold a critical opinion regarding this concept, it may be difficult to persuade clients regarding the concept's merits. R5 commented that wall-mounted solar panels may not be as effective if shadows are covering portions of the panels. R9 also mentioned that in a city with multiple high-rise buildings and other tall structures, there is a high chance for the panels to get blocked by the shadows, thus decreasing their efficiency. R7 and R8 agreed that this is a major barrier which could have architectural, as well as legal implications. Three (Nr=3) respondents claimed that wall-mounted solar panels can be difficult to maintain once installed. R1 stated that without a gondola system or window cleaning system, it would be difficult to maintain and repair the system. R6 and R8 voiced concerns over the cost it would incur for maintenance and repair works as the walls of high-rise buildings are not easily accessible. The interviewees pointed out that maintenance difficulties would be a significant barrier towards adoption in Sri Lanka, particularly in regions outside of the economic hub, Colombo.

Another problem identified by R3, R4, and R8 is that wall-mounted solar panels increase the temperature inside the building. Several interviewees brought up the building orientation as a barrier towards adoption. As the building cannot be rotated according to the path of the sun, wall-mounted solar panels should be installed after checking the maximum angle of effectiveness. Therefore, it would be difficult to apply this technology to all high-rise buildings. Furthermore, there are various elements including windows, balconies, etc, on the walls of high-rise buildings. Wall-mounted solar panels can interfere with the operations of those elements. Especially the apartment buildings facing the sea which have large windows. This type of technology cannot be used for such buildings. Another unique problem identified by R2 is that due to delayed payments by the CEB to those who generate electricity through solar panels and supply electricity to the national grid, potential clients are hesitant to invest in solar panels. Therefore, the probability of investing in a new solar application is bleak.

Table 2 encompasses a summary of the barriers that were identified through this study.

Table 2: Summary of identified barriers

Barrier	**Code**	**Arch.**		**MEP**		**QS**		**CE**		**PM**	**SE**	**Frequency**
		R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	
Permissions from SLSEA	B1										✓	1
Solar trajectory	B2		✓								✓	2
Initial investment return	B3	✓		✓		✓	✓	✓		✓	✓	7

Barrier	Code	Arch.		MEP		QS		CE		PM	SE	Frequency
		R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	
Reflection of sunlight	B4	✓	✓	✓	✓							4
Aesthetic appearance	B5	✓	✓									2
Shadows on the panels	B6					✓		✓	✓	✓		4
Maintenance	B7	✓					✓		✓			3
Increased building temperature	B8			✓	✓				✓			3
Building orientation	B9				✓		✓			✓		3
Blocking other wall elements	B10			✓		✓				✓		3
Late payments to clients	B11		✓									1

4.4 STRATEGIES TO OVERCOME BARRIERS

Multiple respondents stated that a proper policy is needed for wall-mounted solar panels. After consulting with the SLSEA, the authors were informed that yet, the output of the wall-mounted solar panels has not been allowed to connect to the national grid. However, a pilot project has been proposed that has the support of the SLSEA. It was concluded that to enforce a policy, firstly a wall-mounted solar panel project should be done properly with the intervention of the government or by SLSEA or any other subsidiary body and its results should be monitored. According to the observations of the pilot project, problems and strategies should be identified for them and a fitting policy should be implemented so that wall-mounted solar panels can be used properly for construction projects in Sri Lanka.

The main problem for any solar application is the high initial cost. The specific problem with wall-mounted solar panels is that since the efficiency is lower, it takes a relatively longer time to recover the investment. Respondents suggested that through government intervention, tax concessions can be made to reduce the initial cost, thus reducing the investment recovery period. This creates a win-win situation where clients can afford this renewable energy source for a low cost whereas the government can benefit from the increase of solar energy use within the country, which in turn is a long-term economically sustainable solution. The experts further suggested that if wall-mounted solar panel application can be carried out at an industrial scale, there will be a shared risk with mass benefits. Due to the path of the sun, the way the sunlight hits the walls of high-rise buildings changes. Therefore, if solar panels are fixed firmly on the walls of high-rise buildings, the time the solar panels receive sunlight will be limited. As many interviewees said, if the solar panels are installed in an adjustable manner, sunlight can be received on the solar panels for a relatively long time. It can increase the efficiency of wall-mounted solar panels. Electricity generation can be increased by using high-efficiency solar panels.

Another problem identified previously is that the wall-mounted solar panels interfere with the elements on the walls and obstruct the outside view of the people inside the building. One of the strongest objections of both architects was that the aesthetic of the building would be lost due to these wall-mounted solar panels. As a strategy for this, R2 suggested that it is appropriate to use transparent solar panels. This is a very good strategy in terms of aesthetic appearance and visibility. However, transparent solar panels are very expensive. Therefore, if transparent solar panels are used, the initial cost will increase even more. When considering a high-rise building wall, according to the sun's path, the sunlight falls on it only in the morning or evening. Therefore, R3 and R9 suggested that if wall-mounted solar panels can be installed on both sides of the building, the solar panels can capture sunlight at any time of the day. However, R3 further stated that although the amount of electricity generated will be increased, the initial cost will increase by about 80%. To prevent the shadows of other buildings falling from the panels, it was suggested that the panels should be installed at the highest possible points of the buildings.

A major barrier identified was that wall-mounted solar panels reflected sunlight onto other buildings. As a solution, R1 suggested that if the surface can be given a matte-finish surface, the reflection can be prevented. Generally, those who produce electricity by solar panels and contribute to the national grid are paid according to the unit quantity. However, due to reasons such as the current economic crisis in Sri Lanka, these payments have been delayed. R2 suggests that if the payments are paid at an attractive rate, people will invest in wall-mounted solar panels. If wall-mounted solar panels are feasible in Sri Lanka, this would be a good strategy for marketing.

Table 3: Summary of suggested strategies

Strategy	Code	Arch.		MEP		QS		CE		PM	SE	Frequency
		R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	
Carry out a regulated pilot project to enforce a policy on wall-mounted solar panels	S1							✓			✓	2
Provide tax concessions to ease initial investment and speed up return	S2		✓			✓		✓				3
Implement wall-mounted solar panels on industry scale	S3	✓										1
Install panels in an adjustable manner	S4				✓		✓		✓	✓		4
Use transparent solar panels	S5		✓									1
Install panels on multiple sides of the building	S6			✓						✓		2
Install as high as possible	S7			✓		✓						2
Panels with matte-finish surface	S8	✓										1
Timely and sufficient payments to users	S9		✓									1

5. DISCUSSION

In the context of Sri Lanka, the concept of wall-mounted solar panels is entirely novel and untested. This exploratory study aimed to investigate the suitability of this concept for Sri Lanka and bridge the knowledge gap surrounding the adaptability of wall-mounted panels in Sri Lanka. Eleven (Nr=11) significant barriers were discovered through this study. The expert interviewees agreed that adjustable wall-mounted solar panels could be a solution to prevent shadows, blocks and solar trajectory issues (S4). Similar studies (Osigbemeh et al., 2022; Nguyen et al., 2019) have introduced design and mounting implementations for wall-mounted solar panels hence maximum efficiency can be obtained. Therefore, this strategy (S4) can be an effective solution when implementing wall-mounted solar within Sri Lanka. The authors recommend for this strategy to be explored through further research, to investigate the ideal implementation layout for wall-mounted solar panels in Sri Lanka. Certain strategies that were discussed by the respondents are useful to overcome specific barriers, however, they are not feasible in the context of Sri Lanka. For example, installing wall-mounted solar panels on both sides of the building can capture sunlight at different times of the day (S6). However, S6 may not be economically viable for Sri Lanka, where the main concern of clients is the initial cost. Using transparent solar panels (S5) can solve the issue of sunlight reflection, which was the main barrier identified in this study (B4). However, this option is also significantly costly and may not be feasible when applied to Sri Lanka. The most pressing concern within Sri Lanka is the high initial investment associated with wall-mounted solar panels, and the subsequent period of return (B3). Most interviewees expressed doubt whether the invested amount can be recovered within a reasonable time given that the effectiveness of the supplied energy is comparatively less than rooftop solar panels. The same issue was observed by Osigbemeh et al. (2022) in a study on the plausibility of using wall-mounted photovoltaics in inaccessible or restricted rooftops. However, according to Osigbemeh et al. (2022), wall-mounted solar panels displayed an 80% power efficiency on typical sunny days compared to the 100% efficiency of roof-mounted solar. Therefore, the findings present wall-mounted photovoltaics as an efficient alternative to rooftop solar, where the roof area is inaccessible. Additionally, this study suggests that government intervention to provide tax concessions can help ease the burdens of barriers such as B3 and that it would motivate more investment in solar energy (S2).

6. CONCLUSIONS

The construction industry must take proactive measures to enhance sustainability and reduce the energy consumption of its activities. Embracing solar power stands out as a compelling solution in this context. Although Sri Lanka employs solar energy, the concept of wall-mounted solar panels is still novel within the country. This concept has massive space-saving and sustainable potential if it can be utilised for high-rise buildings in Sri Lanka, where the limited rooftop area is often an issue when implementing solar energy. This research acts as an exploratory study which begs the question if wall-mounted solar panels are a feasible option for Sri Lanka. This study aims to investigate the adaptability of the wall-mounted solar panel design concept in high-rise buildings in Sri Lanka. Through this aim, the study shall bridge the knowledge gap of whether the concept is suitable to be pursued in Sri Lanka, with an emphasis on the views of solar energy experts and construction professionals. The first objective of the study was to review the concept of wall-mounted solar panel design, its importance and its availability in Sri Lanka. This objective was achieved through an in-depth literature review which gathered and summarised the existing discourse on wall-mounted solar panels. The knowledge gap, especially in the context of Sri Lanka was highlighted through the literature review. The next objectives were to investigate the suitability and the associated barriers to adopting wall-mounted solar panels in high-rise buildings in Sri Lanka and to propose strategies to overcome the identified barriers. Eleven barriers were identified by this study and nine strategies were proposed. However, some strategies were not entirely feasible for Sri Lanka, especially considering the high cost. This study concludes that while the concept of wall-mounted solar energy has merit, the feasibility must first be tested through a pilot project. As noted by the interviewees as well as through past studies, wall-mounted solar panels present some advantages that must not be overlooked and could even be used in conjunction with rooftop solar panels, where space limitations are an issue. Thus, even if no projects with this concept have been completed in Sri Lanka yet, it would be extremely important to test this concept here as it contributes to sustainability, which is crucial for the building sector. Additionally, it is a viable solution to the energy crisis, which is a global mission for Sri Lanka.

7. REFERENCES

Allouhi, A., Fouih, Y. E., Kousksou, T., Jamil, A., Zéraouli, Y., & Mourad, Y. (2015). Energy consumption and efficiency in buildings: Current status and future trends. *Journal of Cleaner Production*, *109*, 118–130. https://doi.org/10.1016/j.jclepro.2015.05.139

Asdrubali, F., & Desideri, U. (Eds.). (2019). *High efficiency plants and building integrated renewable energy systems*. In Elsevier eBooks (1st ed., pp. 441–595). https://doi.org/10.1016/b978-0-12-812817-6.00040-1

Baidya, S., & Nandi, C. (2020). *Green energy generation using renewable energy technologies*. *In green energy and technology* (pp. 259–276). Springer Singapore. https://doi.org/10.1007/978-981-15-4246-6_16

Bhatia, S. (2014). *Solar devices*. In Elsevier eBooks (pp. 68–93). https://doi.org/10.1016/b978-1-78242-269-3.50003-6

Devi, L. P., & Palaniappan, S. (2017). A study on energy use for excavation and transport of soil during building construction. *Journal of Cleaner Production*, *164*, 543–556. https://doi.org/10.1016/j.jclepro.2017.06.208

Dräger, P., & Letmathe, P. (2022). Value losses and environmental impacts in the construction industry – Tradeoffs or correlates? *Journal of Cleaner Production*, *336*, 130435. https://doi.org/10.1016/j.jclepro.2022.130435

Fellows, R. F., & Liu, A. M. M. (2015). *Research methods for construction*. John Wiley & Sons.

Hussain, C. M. (Ed.). (2018). *Engineered nanomaterials for energy applications*. In Elsevier eBooks (1st ed., pp. 751–767). https://doi.org/10.1016/b978-0-12-813351-4.00043-2

Hussain, C. M., Paulraj, M. S., & Nuzhat, S. (2022). *Source reduction and waste minimization in construction industry*. In Elsevier eBooks (pp. 111–126). https://doi.org/10.1016/b978-0-12-824320-6.00005-8

Jakštas, T. (2020). *What does energy security mean?* In Elsevier eBooks (pp. 99–112). https://doi.org/10.1016/b978-0-12-817688-7.00005-7

Khare, V., Khare, C., Nema, S., & Baredar, P. (2023). *Fundamental and basic principles*. In Elsevier eBooks (pp. 1–33). https://doi.org/10.1016/b978-0-323-85761-1.00005-6

Kiboi, T. M., & Moses, P. M. (2022). Effectiveness of vertically mounted solar panels on buildings - A case study of Radisson Blu Hotel, Nairobi. *2022 IEEE PES/IAS PowerAfrica*. https://doi.org/10.1109/powerafrica53997.2022.9905393

Kurian, J., & Karthi, L. (2021). Building integrated photovoltaics- an overview. *SAFER*, *10*(1). https://doi.org/10.7770/safer-v10n1-art2495

Letcher, T. M. (2022). *Global warming, greenhouse gases, renewable energy, and storing energy*. In Elsevier eBooks (pp. 3–12). https://doi.org/10.1016/b978-0-12-824510-1.00011-8

Mellit, A., & Kalogirou, S. A. (2022). *Solar radiation and photovoltaic systems: Modeling and simulation*. In Elsevier eBooks (pp. 1–41). https://doi.org/10.1016/b978-0-12-820641-6.00001-6

Min, J., Yan, G., Abed, A. M., Elattar, S., Khadimallah, M. A., Jan, A., & Ali, H. E. (2022). The effect of carbon dioxide emissions on the building energy efficiency. *Fuel*, *326*, 124842. https://doi.org/10.1016/j.fuel.2022.124842

Nguyen, L. D. L., Ngoc, S. D., Cong, D. T., Thuong, D. L., Van, S. N., Vu, N. H. M., & Le, N. T. (2019). *Facade integrated photovoltaic systems: Potential applications for commercial building in Vietnam.* In 2019 International Conference on System Science and Engineering (ICSSE). https://doi.org/10.1109/icsse.2019.8823134

Osigbemeh, M. S., Asaolu, O., & Nwachukwu, A. N. (2022). Sustainable solar power from wall mounted photovoltaics. *Energy Systems*, *14*(4), 1007–1022. https://doi.org/10.1007/s12667-021-00497-x

Peng, J., Yan, J., Zhai, Z., Markides, C. N., Lee, E. S., Eicker, U., Zhao, X., Kuhn, T. E., Sengupta, M., & Taylor, R. A. (2020). Solar energy integration in buildings. *Applied Energy*, *264*, 114740. https://doi.org/10.1016/j.apenergy.2020.114740

Pérez, M., Fthenakis, V., Kim, H. C., & Pereira, A. O. (2012). Façade–integrated photovoltaics: A life cycle and performance assessment case study. *Progress in Photovoltaics*, *20*(8), 975–990. https://doi.org/10.1002/pip.1167

Roberts, S., & Guariento, N. (2009). 4. *Design of the building envelope*. In De Gruyter eBooks (pp. 43–60). https://doi.org/10.1007/978-3-0346-0486-4_4

Saadatian, O., Haw, L. C., Sopian, K., & Salleh, E. (2013). A state of the art review of solar walls: Concepts and applications. *Journal of Building Physics*, *37*(1), 55–79. https://doi.org/10.1177/1744259113479336

Salama, F. (2018). *An analysis of the benefits of vertical solar photovoltaic systems and the effect of artificial ground cover on energy output*. University of Saskatchewan.

Saunders, M. N. K., Lewis, P., & Thornhill, A. (2019). *Research methods for business students*, (8th ed). https://www.researchgate.net/publication/330760964_Research_Methods_for_Business_Students_Chapter_4_Understanding_research_philosophy_and_approaches_to_theory_developmentŞenpinar, A. (2018). *Optimization of slope angles of photovoltaic arrays for different seasons*. In Elsevier eBooks (pp. 507–521). https://doi.org/10.1016/b978-0-12-813734-5.00028-7

Sharma, A. K., & Kothari, D. P. (2017). Solar PV facade for high-rise buildings in Mumbai. International *Journal of Civil Engineering Research*, *8*(1), https://www.ripublication.com/ijcer17/ijcerv8n1_02.pdf

Smith, B., Dvorak, J. S., Semmens, K., & Colliver, D. G. (2022). Using a computer-based selection model for sizing of solar panels and battery back-up systems for use in a floating in-pond raceway. *Aquacultural Engineering*, *97*, 102238. https://doi.org/10.1016/j.aquaeng.2022.102238

Soga, T. (2006). *Fundamentals of Solar Cell*. In Elsevier eBooks (pp. 3–43). https://doi.org/10.1016/b978-044452844-5/50002-0

Yan, J., Yang, Y., Campana, P. E., & He, J. (2019). City-level analysis of subsidy-free solar photovoltaic electricity price, profits and grid parity in China. *Nature Energy*, *4*(8), 709–717. https://doi.org/10.1038/s41560-019-0441-z

Zhou, Z., He, Y., Jia, L., & Zhang, X. (2019). Feasibility of balcony wall-mounted solar water heating system in high-rise residential buildings. *Journal of Engineering Science and Technology Review*, *12*(6), 142–147. https://doi.org/10.25103/jestr.126.18