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ECONOMIC PERFORMANCE OF GREEN WALLS: A SYSTEMATIC REVIEW

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ABSTRACT

Green walls are becoming an interesting solution to address the potential issues due to loss of greenery in the urban built environment. Even though green walls offer numerous benefits, the application pace of this concept seems slow in many parts of the world including Sri Lanka, which could be primarily due to the perception that the construction of green walls may involve additional costs compared to conventional walls and due to lack of awareness of its performance. This has driven the recent researchers to investigate the economic performance of green walls. However, those studies are limited to given local contexts, thus, the knowledge is scattered. Therefore, this paper aims to explore the economic performance of green walls in the global context collectively using a systematic review towards understanding the differences. Filtering the search for the period of 2010 to 2022 offered 15 out of 103 research articles suitable for the analysis. The cost data extracted shows high variability related to different characteristics of green walls, building envelopes, and climatic conditions. According to the review, the maintenance stage accounts for the highest portion of the Life Cycle Cost (LCC) in any type of green wall. The direct green façade is the cheapest option with lowest LCC compared to the indirect and living wall types while the living wall is the expensive type due to presence of more components. The review further confirms that in most instances, the economic benefits of green walls; increase property value, façade longevity, tax incentives, and energy-saving tend to offset the cost of green walls. It is expected that this collective review outcome would better guide the decision-making process of green wall implementation in a given context.

Keywords: *Benefits; Costs; Economic performance; Green walls; Systematic Review.*

1. INTRODUCTION

With the increment of population growth and the rapid development of urbanisation, environmental issues have drawn worldwide attention (Chuai, et al., 2021). According to the United Nations (2018), urban population may rise 60% by 2030 and accounts for 60–80%, 75%, and more than 60% of global energy consumption, carbon emissions, and resource use, respectively. Furthermore, if there are no alterations to improve the energy efficiency of buildings, the demand will be increased by 50% for global building energy from 2018 to 2050 (US Energy Information Administration [USEIA], 2019). In addition to the energy crisis, global warming, climatic changes, health problems, loss of biodiversity and rising risk of natural disasters are a few of the many challenges that

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current society facing, giving rise to the integration of natural vegetation into the built environment (Olubunmi, et al., 2016). Therefore, rain gardens, street trees, urban drainage systems, green roofs, and green walls are effective solutions for mitigating and avoiding those issues in urban areas (Teotonio, et al., 2021). Green roofs and green walls can be considered as the most preferred solution than others due to the scarcity of land and the numerous benefits in terms of environmental, economic, and social aspects (Manso, et al., 2021). Of them, green walls have a greater potential to yield positive outcomes than green roofs because the surface area of the walls of a multi storey building is greater than the area of roof (Olubunmi, et al., 2016).

Green walls are referred to as all forms of vegetated wall surfaces and can be classified into two main categories as green facades and living wall systems based on their method of construction (Manso and Castro-Gomes, 2015). Green facades are based on a climbing plant directly attached to the wall (Direct green facades) or supported by structures such as steel cables or trellis (Indirect green façade) (Manso, et al., 2021). The living wall system is more complicated with a prefabricated or pre-vegetated system on a modular panel that contains growing media with balanced nutrients (Huang, et al., 2019). Green walls provide multiple services to three sustainable pillars: environment, economy, and society. In terms of environmental benefits, absorption of air pollutants, and improved air quality (Teotonio, et al., 2021), urban noise absorption, mitigating urban heat island effect (Manso, et al., 2021), provide habitats for small insects and birds, and urban wildlife protection (Silva, et al., 2018) are prominent. From the perspective of economic benefits, green walls enhance buildings' performance by increasing property value (Dong and Huang, 2021) and building durability (Almeida, et al., 2020). Furthermore, reduce the energy consumption for heating, ventilation, and air conditioning by maintaining the heat transfer between internal and external environments through plants (Zazzini and Grifa, 2018). In addition to environmental and economic benefits, social benefits comprise of providing quality and healthy life, spaces for recreational use (Teotonio, et al., 2021), and improving aesthetics (Rosasco and Perini, 2018).

Although benefits which green walls offer, the wider application of this concept is hindered by several factors: high initial and maintenance cost, lack of public awareness on the green wall concept, high technology, and breading unwanted pests, etc. (Naumann, et al., 2011). Amongst these barriers, the high initial and maintenance cost of green walls compared to conventional walls is evident as a major concern. For example, Chew and Conejos (2016) noted that lack of awareness and the high initial cost are major barriers that limit the widespread application of the green wall concept. Similarly, a survey carried out to identify the possible reason for the low adoption of green walls concluded that most people hold onto the perception that the high initial cost of green walls is relative to conventional walls (Wong, et al., 2010). Therefore, a through account and a proper evaluation of the economic performance of the green wall concept will help to encourage the green wall application.

The foregoing review confirms that much work has been done on the economic performance of the green wall concept in the global context over the last decade. However, those studies are limited to a specific region, climate, or context. Hence, reviewing the available literature will help to identify the global trends with respect to the economic performance of green walls and whereby it can assure the developers and investors on deciding on the application of green walls. Therefore, this paper aims to explore the changes in the economic performance of green walls in the global context using a systematic review approach.

2. RESEARCH METHODS: SYSTEMATIC REVIEW

The systematic review technique was used to carry out the literature search in this study as it is widely practiced among several methods. Rather than selecting random literature, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method was adopted to improve the quality of the study. According to Benachio, et al. (2020), the PRISMA guideline consists of a four-phased flow diagram where it passes through the phases of identification, screening, eligibility, and inclusion.

2.1 SEARCH STRATEGY

Initially, the research question of "What is the level of the economic performance of green walls in the global context?" was developed using the PICO (Population, Intervention, Comparator, and Outcome) search strategy tool (Cooke, et al., 2012). Since the research question focuses on economic performance, which is more towards quantitative outcomes, the PICO search strategy enables defining a quantitative research question and search terms, laying the pathway for a systematic search strategy (Schardt, et al., 2007, as cited in Cooke, et al., 2012). Accordingly, the PICO elements of the research question formulated for the study were identified: global context as the study population, green walls as the intervention, and economic performance as the expected outcome. As the study intends to systematically explore the concept of green walls where it is not necessary to consider an alternative to the identified intervention, i.e., green walls, the comparator element was eliminated from the study (Cooke, et al., 2012). Following, a basic logic grid was developed to perform an initial search to identify the relevant key and index terms to include in the comprehensive search strategy. Table 1 provides the basic logic grid alone with the alternative terms identified for the PICO elements. Here, the term global context was not included in the logic grids as the intention is to retrieve publications covering the whole world.

Table 1: Logic grid with identified keywords added

Population	Intervention	Outcome	
Global context	Green wall	Economic	Performance
	Green façade	Cost	Capability
	Vertical greenery system	Cost?benefit	Feasibility
	Living wall	Life?cycle?cost	Appraisal
	Green garden	Lifecycle?cost	Analysis
		Financial	Evaluation
			Assessment
			Sustainability
		Sensitivity analysis	

As indicated in Table 1, wild cards such as question mark (?) were introduced to several terms to maximize the search results in literature databases. When developing the final search strategy, quotation marks were used to get the exact term and the Boolean operator "AND" was used to combine the PICO elements while "OR" was used to link synonyms identified for each element. Once all the search terms were identified and finalised, the final search string was developed as follows.

(("green wall" OR "green facade" OR "vertical greenery system" OR "living wall" OR “green garden”) AND (“economic performance” OR “economic capability” OR “economic feasibility” OR “economic appraisal” OR “economic analysis” OR “economic evaluation” OR “economic assessment” OR “economic sustainability” OR “cost performance” OR “cost capability” OR “cost feasibility” OR “cost appraisal” OR “cost analysis” OR “cost evaluation” OR “cost assessment” OR “cost?benefit performance” OR “cost?benefit capability” OR “cost?benefit feasibility” OR “cost?benefit appraisal” OR “cost?benefit analysis” OR “cost?benefit evaluation” OR “cost?benefit assessment” OR “life?cycle?cost performance” OR “life?cycle?cost capability” OR “life?cycle?cost feasibility” OR “life?cycle?cost appraisal” OR “life?cycle?cost analysis” OR “life?cycle?cost evaluation” OR “life?cycle?cost assessment” OR “lifecycle?cost performance” OR “lifecycle?cost capability” OR “lifecycle?cost feasibility” OR “lifecycle?cost appraisal” OR “lifecycle?cost analysis” OR “lifecycle?cost evaluation” OR “lifecycle?cost assessment” OR “financial performance” OR “financial capability” OR “financial feasibility” OR “financial appraisal” OR “financial analysis” OR “financial evaluation” OR “financial assessment” OR “financial sustainability” OR “sensitivity analys?s”))

2.2 STUDY SELECTION

Within systematic reviews, when searching for relevant references, it is advisable to use multiple databases. However, searching databases is laborious and time-consuming, as syntax of search strategies are database specific (Bramer, et al., 2017). Given the time and resources constraints and the optimal combination of databases, the current study performed systematic searches in three databases: Web of Science, Scopus, and Science Direct, as those comprised of high-ranking and indexed scholarly journals and conference proceedings. Furthermore, a manual search was also conducted to identify any other remaining seminal works which satisfied the research question of this study. Once the systematic searches were conducted in above-mentioned bibliographic databases and manually, the search string was further refined by introducing relevant filters given in Table 2.

Table 2: Filters assigned for the literature search

Criteria	Filters	Rationale
Search fields	Title, Abstract, Keywords	To extract all possible and relevant records
Publication year	From 2010 to 2022	Avoiding out of date results
Subject/Research area	Environmental science, Engineering, Social science, Material science, Decision Science, Economics, Econometrics and Finance	Research areas related to construction and built environment
Document type	Article, Proceedings papers	-
Language	English	English is the international and the universal language

Finally, all the records were imported to the Mendeley software for screening and systematic analysis.

2.3 DATA EXTRACTION

The PRISMA flow diagram (see Figure 1) was used to present the process that adapted to extract the relevant data from the records retrieved via structured searches performed in bibliographic databases and manually (Liberati, et al., 2009).

The complete search found 103 records: 11, 27, 56, and 9 journal articles and conference proceedings from the Web of Science, Scopus, Science Direct, and manual search citation, respectively. From these records, 24 duplicate records were removed. The remaining 79 records were screened using the titles, keywords and abstracts and found 53 of them to have no relevance to the research question of this study. Subsequently, the remaining 26 records were sought for full-text; full-texts were re derived for all records; thus all 26 publications were forwarded for the in-depth review. Of 26, 11 publications were excluded as they are not dedicated to the economic performance of green walls which resulted in 15 included studies. Along with, the geographic location, methodology, and publication year of the filtered studies were also considered to derive conclusions of the current study.

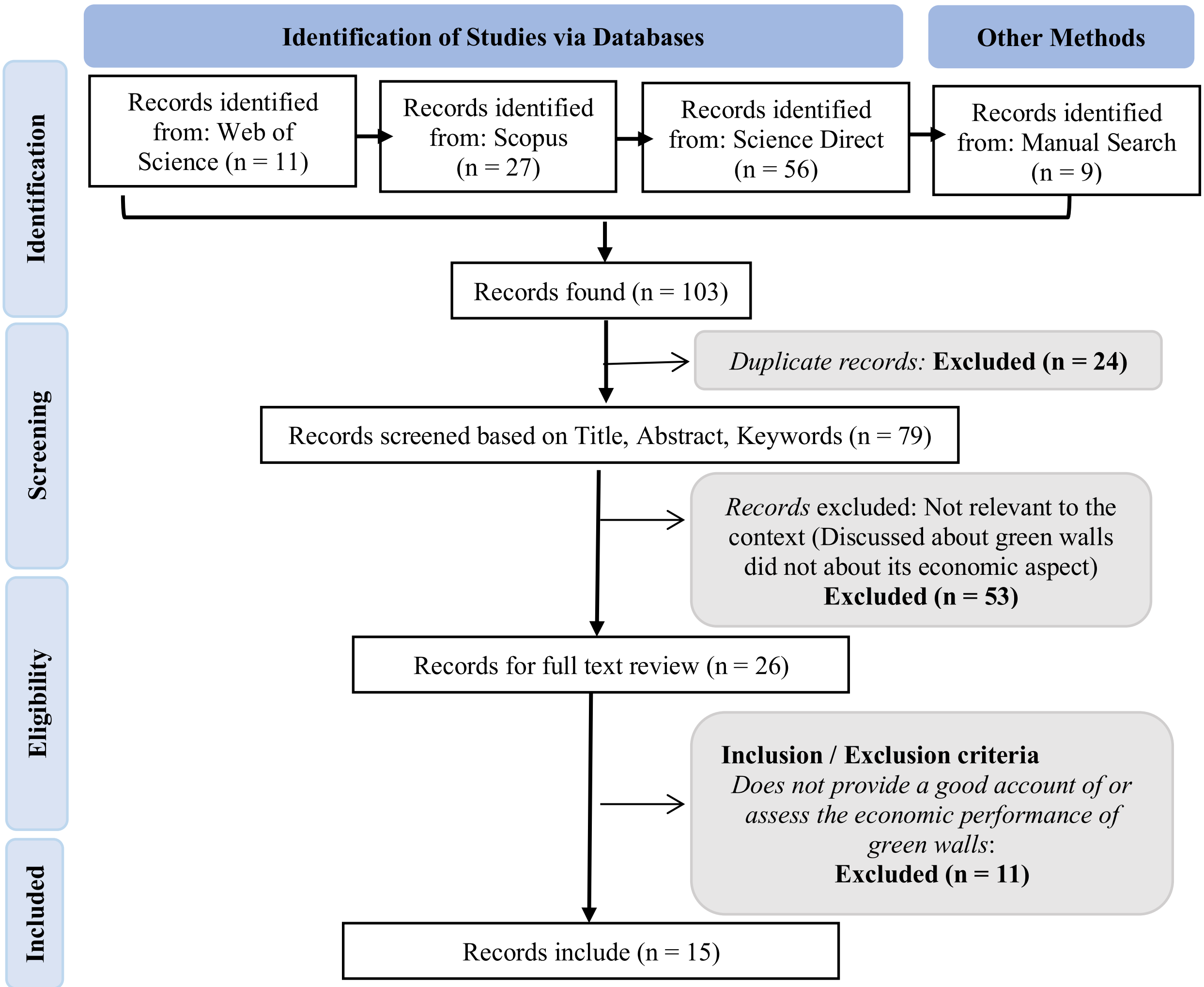

Figure 1: Flow diagram of study selection

The 15 articles filtered are journal publications. Classification of the study selection based on their year of publication is presented in Figure 2.

As observed in Figure 2, there have been increased publications in recent years, 2018, 2019, and 2021. This seems to indicate that the investigations into the subject area in concern are emerging in the recent past.

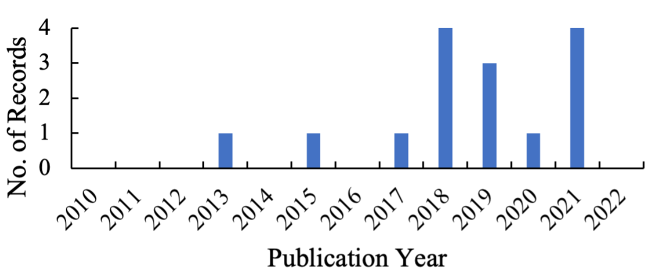

Figure 2: Analysis of the selected research contributions

3. RESULTS AND DISCUSSION

The key focuses discussed in the articles collected are summarised Table 3.

Table 3: Summary of key focuses of the selected research articles

Area	Sources		
		No.	%
Economic benefits of green walls	(Teotonio, et al., 2021; Rosasco, 2018; Manso, et al., 2021; Santi, et al., 2019; Shazmin, et al., 2017; Zazzini and Grifa, 2018; Rosasco and Perini, 2018; Almeida, et al., 2020; Perini and Rosasco, 2013; Haggag and Hassan, 2015)	10	67%
Economic performance comparison among different green wall types	(Huang, et al., 2019; Almeida, et al., 2020; Silva, et al., 2018; Perini and Rosasco, 2013; Dong and Huang, 2021)	5	33%
Economic performance assessment		7	47%
LCC Analysis	(Huang, et al., 2019; Dong and Huang, 2021; Silva, et al., 2018	3	20%
CBA	(Rosasco and Perini, 2018; Almeida, et al., 2020; Perini and Rosasco, 2013; Haggag and Hassan, 2015)	4	27%

As observed from Table 3, 10 out of 15 papers, which is the highest number of studies have researched about economic benefits of green walls. 7 out of the 15 papers have assessed the economic performance of green walls using LCC (3) and CBA (4) methods. Of those researches, 5 papers have compared the economic performance of different green wall types while the rest of them have focused only on one particular type of green wall. As the next step of the systematic review, the search results were further analysed and synthesized their contents to extract the knowledge on (1) life cycle stages and respective cost components of green walls and (2) the economic benefits of green walls. The outcome of this analysis is presented in the following section.

3.1 LIFE CYCLE COST STAGES AND COST COMPONENTS OF GREEN WALLS

Of the reviewed papers, 7 out of 15 papers have discussed the life cycle stages of green walls along with their cost components that can be considered in the assessment of economic performance. Table 4 illustrates the life cycle stages and the respective cost components referred in the studies.

Table 4: Life cycle cost stages and components of green walls used in different studies

Sources	LCC Stages	LCC components
Perini and Rosasco, (2013)	Initial	Plants, Pot, panels, support system, irrigation system, installation, transportation
	Maintenance	Pruning, cladding renovation, irrigation, plants replacement, pipe replacement, panels replacement
	Disposal	Green layer disposal
Haggag and Hassan (2015)	Initial	Plants, growing media, installation, irrigation system
	Maintenance	Irrigation
Rosasco and Perini (2018)	Installation	Panels, supporting system, plants, transport, construction
	Maintenance	Pruning, plants replacement, pipe replacement
	Disposal	Disposal
Silva, et al. (2018)	Construction	Not specified the cost items further
	Maintenance	
	Demolition	
Huang, et al. (2019)	Initialisation	Structure, plants, pot, panel, growing media, irrigation system, drainage system, fertilizers, electricity, water, manpower
	Installation	Transport, installation, electricity, water, manpower
	Operation & Maintenance	Replacement cost of materials, mainly for plants and irrigation systems, fertilizer, electricity, water, manpower
	Disposal	Transport, manpower
Almeida, et al. (2020)	Installation	Not specified the cost items further
	Maintenance	
	Replacement	
Dong and Huang (2021)	Design	Design and strategic planning
	Construction	Cost during the construction, including labour and material
	Maintenance	Project operation, maintenance, updates, replacement, and disassembly
	Finance	Project financial support

Perini and Rosasco (2013) and Rosasco and Perini (2018) have indicated that the Life Cycle Cost (LCC) of green walls can be broadly classified into three categories as initial, maintenance, and disposal. Similarly, Huang, et al. (2019) also have identified three (03) stages where the initial stage was divided into two subcategories: (1) initialisation (off-site preparation) and (2) installation (on-site preparation) while other two (02) stages included operation and maintenance and disposal. In the case of operation and maintenance, there was no clear separation of operational cost items and maintenance cost items identified. In another instance, Haggag and Hassan (2015) have carried out a cost-benefit analysis where authors considered only two stages which are initial and maintenance while Silva, et al. (2018) considered the LCC of green walls in terms of three components: construction, maintenance, and demolition. Almeida, et al. (2020) used the term replacement as the last LCC stage. However, the LCC stages considered by Dong and Huang (2021) are slightly different from the above-mentioned studies. The stages include design, construction, maintenance, and finance.

According to the above review the three main LCC stages of green walls can be identified as initial, maintenance, and end life and the cost components belonging to each stage are given in Table 5.

Table 5: Summary of the life cycle cost stages and components of green walls

LCC Stage		Cost component
Initial	**Initialisation (off-site preparation)**	Taking care of plants, support system, structure, plants, pot, panel, growing media, irrigation system, drainage system, fertilisers, electricity, water, manpower
	Installation (on-site)	Transport to the site, installation on-site, electricity, water, manpower, design
Maintenance		Pruning, cladding renovation, irrigation, plants replacement, pipe replacement, panels replacement, electricity, water, manpower
End life		Green layer disposal, transport, replacement, manpower

(Sources: Perini and Rosasco, 2013; Haggag and Hassan, 2015; Rosasco and Perini, 2018; Silva, et al., 2018; Huang, et al., 2019; Almeida, et al., 2020; Dong and Huang, 2021)

3.1.1 Initial

Initial costs of green walls can be computed through the Bills of Quantities or obtained from green wall suppliers. According to Perini and Rosasco (2013) who examined the initial cost of different green wall systems in Italy (Mediterranean climate), the initial cost of green walls varies with the green wall type. The initial cost of the direct green facade is between 30 and 45 €/m2 and it is the cheapest option in terms of the initial cost. When considering the initial cost of the indirect green façade made of High-Density Polyethylene (HDPE) is about 125 €/m^2 while steel based is about 216 €/m^2. If an indirect green façade is combined with the planter boxes, then the initial cost further increases. However, a living wall can reach a cost of 315 €/m2, the most expensive type, amongst all types. Similarly, Dong and Huang (2021) examined the LCC of a green facade (not specified whether direct or indirect) and four different types of living walls (Blanket, Pocket style, Hanging containers, and Modular containers) in China and revealed that the green façade accounts for less initial cost compared to all types of living walls considered. Furthermore, the initial cost of living walls is increased with the material involvement; Hanging containers, modular containers, pocket style, and blanket, respectively. It was further evidenced by Silva, et al. (2018) that the initial cost of living wall considered in the study is fifteen times the initial cost of green façade (not specified whether direct or indirect) in Portugal. Similarly, Almeida, et al. (2020), concluded that the initial cost of a green façade in both indoor and outdoor are less compared to the living walls installed in both indoor and outdoor. Conversely, Huang, et al. (2019) researched about three types of green walls which are mostly available in Singapore and showed that the cost involved in the initial stage is 15%, 18%, and 25% of the total cost in carrier system (Living wall), planter system (indirect green façade with pot), and support system (indirect green façade with frame and mesh), respectively. This could be due to the material involvement of the different green wall systems.

Hence, it can be concluded that the initial cost of the green walls mainly depends on the geographical location, type of plants species used, materials used for the structural support, and system (direct, indirect, living wall). In terms of green wall types, a green façade; direct or indirect, is less expensive in terms of initial cost compared to a living wall. However, with the types of materials used in the different green wall systems, especially indirect and living wall types, the initial cost contribution can change. Direct green façade accounts for low initial cost as it consists of less components contributing to costs of green walls.

3.1.2 Maintenance

As observed from Table 4, pruning, cladding renovation, plants, pipe, and panel renovation are some of the main cost components in the maintenance stage. Generally, climate conditions and plant selection are the two main factors that determine the maintenance conditions (Rosasco, 2018). Some climatic conditions require more irrigation and re-planting than other conditions. However, choosing native plant species can reduce the irrigation needs and other associated costs. In the initial years, green walls need more irrigation and re-planting due to plant adaptation (Huang, et al., 2019). In addition, time intervals for each maintenance activity affect the whole maintenance cost. As per the maintenance cost considered by Perini and Rosasco (2013) for different green wall systems in Italy, the maintenance cost of green walls is varied with the system. The maintenance cost of a direct green façade mainly consists of the cost of pruning; hence the cost is less compared to other types. In addition to pruning, the indirect green façade system needs the replacement of materials used for the support structure. However, in the living wall system due to vegetation density and diversity, more material involvement can be seen and thereby responsible for high maintenance costs as well. The above authors further added that in any case, maintenance cost contributes significantly to its LCC, on average 51%-78%. The findings of Almeida, et al. (2020) indicated that the maintenance cost of a living wall is twelve times higher than the green facade while Silva, et al. (2018) stated that it is sixteen times higher. Similarly, Huang, et al. (2019) indicated that the operation and maintenance cost together contribute significantly to the LCC of green walls, 84%, 81%, and 74% respectively for the carrier system (Living wall), planter system (indirect green façade with pot), and the support system (indirect green façade with frame and mesh).

The foregoing review concludes that direct green façade has less maintenance cost than the living wall system due to the types of materials used. However, irrespective of the types of green walls, the maintenance cost consumes the largest part of the LCC of any green wall system.

3.1.3 End Life

End life cost of green walls normally includes the removal of all plants, substrate, support layers, and transportation (Perini and Rosasco, 2013). As per Perini and Rosasco (2013), the disposal cost of green walls also depends upon the green wall type. For example, direct green façade, indirect green façade (HDPE), indirect green façade (Steel), indirect green façade (HDPE with planter boxes), indirect green façade (Steel with planter boxes), and living wall account for the disposal cost of about 31 € / m^2, 198 € / m^2, 200 € / m^2, 203 € / m^2, 206 € / m^2, and 219 € / m^2, respectively. Similarly, Huang, et al. (2019) stated that the living wall system involves high disposal cost compared to the indirect green façade system (Planter and support systems). This higher disposal cost of living walls could be due to the diversity of the materials involved in living walls (Radiac, et al., 2019). However, in any type of green walls, the end life cost contribution to the whole life cycle cost is about 1%.

3.1.4 Total Life Cycle Cost

As discussed above, having considered the cost at each stage of the life cycle, Perini and Rosasco (2013) concluded that the direct green façade is the cheapest green wall type in Mediterranean climate mainly due to it contains a smaller number of components. The authors further stated that the living wall systems have much higher LCC compared to indirect and direct green façades. Similarly, Huang, et al. (2019) identified the living wall system as an expensive green wall type compared to indirect green façade in hot and humid climate in Singapore. This is due to the high installation, maintenance, and disposal cost of living walls with its additional cost elements compared to the other two types. It was further evidenced in Portugal (Silva, et al., 2018) and China (Dong and Huang, 2021) that the total Net Present Value (NPV) of the living wall is higher compared to the green façade.

When considering the indirect green façade type, the LCC varies with the material involvement. For example, as per the result of Perini and Rosasco (2013) study in Italy, the LCC of indirect green façade made by steel is higher than the indirect green façade made by HDPE. In case, if the indirect green façade is combined with the planter boxes, the total LCC further increases. Similarly, Huang, et al. (2019) considered two indirect green façade systems; (1) planter system and (2) support system and found that the planter system results in higher Net Present Value (NPV) than the support system in Singapore.

Thus, in considering the total LCC, the living wall involves higher costs compared to other two types and the direct green façade is the cheapest option.

3.2 ECONOMIC BENEFITS OF GREEN WALLS

From the reviewed papers, 10 out of 15 papers have discussed the economic benefits of green walls. Out of 10 studies, 4 studies have quantitatively assessed the economic benefits in their CBA calculations (Refer Table 3). The remaining 6 studies qualitatively identified and presented the economic benefits of green walls. As per the review, there are five (05) economic benefits: enhancing property value, increasing building/facade durability, rental saving, tax incentives, and energy savings for heating and cooling purposes.

Enhancing property value and energy savings for heating and cooling purposes are the mostly assessed benefits in CBA studies while other benefits are rarely assessed.

According to Perini and Rosasco (2013), the economic benefits of green walls differ with green wall types. For example, in Italy, the annual energy saving in direct green façade, indirect green façades made of HDPE and indirect green façades made of steel are equal (1,164 €/year) while indirect green façades made of HDPE & planter boxes and indirect green façade made of steel & planter boxes are equal (980 €/year) but the cost of these two types of indirect green facades (later) is less than the direct green façade and former indirect green façades (HDPE and Steel). The living walls contribute to energy saving of 1,870 €/year, the highest saving potential type of green wall. When considering the benefits of façade durability and enhancing property value cost of this study, it is gradually increased with the green wall types of direct, indirect (HDPE and steel), indirect (HDPE + planter boxes and steel + planter boxes), and living wall, respectively. Similarly, Almeida et al. (2020) study results showed that there is a higher property value increment with living walls than with green facades.

Although Haggag and Hassan (2015) and Rosasco and Perini (2018) considered the energy-saving benefit, there was no comparison between green wall types. The studies focused only on living walls. However, those two studies also evidenced that the living walls account for energy saving, rental saving, and enhancing property value. Furthermore, According to Rosasco and Perini (2018), tax incentives of green walls play an important role in the economic assessment of green walls. When tax reduction is introduced, the net results (i.e. NPV) become positive and thereby can increase the number of investors engaged in green wall implementation.

As evidenced the amount of benefit offered by the green wall types differ from context to context. Since there were limited CBA studies, it is difficult to conclude about the extent of potential benefits of types of green walls. However, the findings of previous studies considered evidence that the costs of green walls can offset the economic benefits. For example, Haggag and Hassan (2015) showed that the cost of a living wall is 58US$/m^2 while the total cost of benefits offered (reduction of cooling load, rental saving and increase property value) by a living wall is 67.23US$ through CBA. It was further evidenced by Perini and Rosasco (2013) and Rosasco and Perini (2018), with positive NPVs (that is when income prevails on cost).

4. CONCLUSIONS

This paper has presented the results of the systematic review carried out on the available studies regarding the economic performance of green walls. The systematic review determined that the annual maintenance cost of green walls consumes a large share of the LCC of any type of green wall and most of the time annual benefits of green walls offset the cost incurred from initialisation to disposal of a green wall system. Compared to maintenance cost of the system, contribution of initial and disposal costs is less. The analysis further revealed that among the green wall types, direct green façade is economical in terms of LCC while living walls are most expensive. This is due to materials involved in the construction of a direct green façade is comparatively less than the living walls. However, with the variation of the materials involved in the different green wall systems, especially indirect and living wall types, the total cost can change. Though the cost of green walls increases with direct, indirect, and living walls, as per the reviewed papers, living walls are responsible for gaining more economic benefit compared to direct and indirect green façades. As per the systematic review, it seems to be most of the studies that discussed the economic performance of green walls belong to

Italy and Singapore context. Since the costs and benefits of green walls could vary with climatic condition, variety of plant species used, materials used for the support structure, etc. It is expected that the future studies would perform a comprehensive assessment of costs and benefits of green walls with respect to the climatic condition, plant species used, materials used for the support structure, etc.

5. ACKNOWLEDGEMENT

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6. REFERENCES

Almeida, C., Teotónio, I., Silva, C.M. and Cruz, C.O., 2020. Socioeconomic feasibility of green roofs and walls in public buildings: the case study of primary schools in Portugal. *The Engineering Economist,* pp. 1-24.

Benachio, G.L.F., Freitas, M.D.C.D. and Tavares, S.F., 2020. Circular economy in the construction industry: A systematic literature review. *Journal of Cleaner Production,* 260, p. 121046.

Bramer, W.M., Rethlefsen, M.L. and Kleijnen, J., 2017. Optimal database combinations for literature searches in systematic reviews: a prospective exploratory study. *Systematic Reviews,* 6(1), pp.1-12.

Chew, M.Y.L. and Conejos , S., 2016. Developing a green maintainability framework For green walls in Singapore. *Structural Survey,* 34(4-5), pp. 379-406.

Chuai, X., Lu, Q., Huang, X., Gao, R. and Zhao, R ., 2021. China's construction industry linked economy-resources-environment flow in international trade. *Journal of Cleaner Production,* 278, pp. 1-11.

Cooke, A., Smith, D. and Booth, A., 2012. Beyond PICO: the SPIDER tool for qualitative evidence synthesis. *Qualitative Health Research,* 22(10), pp. 1435-1443.

Dong, N. and Huang, F., 2021. Cost analysis of vertical greenery in urban complex. *International Journal of High-Rise Buildings,* 10(1), pp. 29-34.

Haggag, M. and Hassan, A., 2015. Cost-benefit analysis of living wall systems on school building skins in a hot climate. *Energy and Sustainability V: Special Contributions,* 1, pp. 3-11.

Huang, Z., Lu, Y., Wong, N.H. and Poh, C.H., 2019. The true cost of "greening" a building: life cycle cost analysis of vertical greenery systems (VGS) in tropical climate. *Journal of Cleaner Production,* 228, pp. 437-454.

Huang, Z., Tan, C.L., Lu, Y. and Wong, N.H., 2021. Holistic analysis and prediction of life cycle cost for vertical greenery systems in Singapore. *Building and Environment*, 196, p. 107735.

Liberati, A., Altman, D.G., Tetzlaff, J., Mulrow, C., Gøtzsche, P.C., Ioannidis, J.P. and Moher, D., 2009. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *Journal of Clinical Epidemiology,* 62(10), pp. e1-e34.

Manso, M. and Castro-Gomes, J., 2015. Green wall systems: A review of their characteristics. *Renewable and Sustainable Energy Reviews,* 41, pp. 863-871.

Manso, M., Teotónio, I., Silva, C.M. and Cruz, C.O., 2021. Green roof and green wall benefits and costs: A review of the quantitative evidence. *Renewable and Sustainable Energy Reviews*, 135, p.110111.

Naumann, S., Davis, M., Kaphengst, T., Pieterse, M. and Rayment, M., 2011. Design, implementation and cost elements of Green Infrastructure projects. *Final report, European Commission, Brussels*, 138.

Olubunmi, O.A., Xia, P.B. and Skitmore, M., 2016. Green building incentives: A review. *Renewable and Sustainable Energy Reviews,* 59, pp. 1611-1621.

Perini, K.and Rosasco, P., 2013. Cost-benefit analysis for green façades and living wall systems. *Building and Environment,* 70, pp. 110-121.

Radić, M., Brković Dodig, M. and Auer, T., 2019. Green facades and living walls - A review establishing the classification of construction types and mapping the benefits. *Sustainability*, 11(17), p. 4579.

Rosasco, P., 2018. Economic benefits and costs of vertical greening systems. *Nature Based Strategies for Urban and Building Sustainability,* pp. 291-306.

Rosasco, P. and Perini , K., 2018. Evaluating the economic sustainability of a vertical greening system: a cost-benefit analysis of a pilot project in mediterranean area. *Building and Environment,* 142, pp. 524-533.

Santi, G., Bertolazzi, A., Croatto, G. and Turrini, U., 2019. Vertical turf for green facades: A vertical greenery modular system integrated to the building envelope. *Journal of Green Building,* 14(4), pp. 111-132.

Shazmin, S.A.A., Sipan, I., Sapri, M., Ali, H.M. and Raji, F., 2017. Property tax assessment incentive for green building: energy saving based model. *Energy,* pp. 329-339.

Silva, C.M., Serro, J., Dinis Ferreira, P. and Teotónio, I., 2019. The socioeconomic feasibility of greening rail stations: a case study in lisbon. *The Engineering Economist*, 64(2), pp. 167-190.

Teotonio, I., Silva, C.M. and Cruz, C.O., 2021. Economics of green roofs and green walls: A literature review. *Sustainable Cities and Society,* 69, p. 102781.

United Nations, 2018. *Goal 11: Make cities inclusive, safe, resilient and sustainable..* [Online] Available from: https://www. un. org/sustainabledevelopment/cities

USEIA, 2019. *International energy outlook 2019 with projections to 2050,* US Energy Information Administration.

Wong, N.H., Tan, A.K., Chen, Y., Sekar, K., Tan, P. Y., Chan, D., Chiang, K. and Wong, N.C., 2010. Thermal evaluation of vertical greenery systems for building walls. 45, pp. 663-672.

Zazzini, P. and Grifa , G., 2018. Energy performance improvements in historic buildings by application of green walls: Numerical analysis of an Italian case study. *Energy Procedia,* 148, pp. 1143-1150.