Study of Vertical Greening System Implementation at Flyover Structure in DKI Jakarta

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Abstract

DKI Jakarta is an urban area with a high population density during working hours, reached 219 people/ha in 2017. This population density encouraged change in green open space to be roads and high-rise buildings, as well as increased exhaust emissions from motorized vehicles. As a result, urban heat island phenomenon has emerged in several locations such as the Jagorawi Toll Road, Cempaka Putih, and Kemayoran. Efforts have been made to reduce and mitigate these impacts by implementing vertical greening system at the flyover structure in DKI Jakarta. However, the temperature in DKI Jakarta continued to rise reaching >41 °C in 2019 as the highest record. The continuous increase in temperature proved that the implementation has not been maximized. This study was conducted for the purpose of identifying the benefits and challenges of the application of vertical greening system at the flyover structure and analyzed existing condition of the implemented vertical greening system at the flyover structure in DKI Jakarta. The method used to achieve those purposes was survey by questionnaire and interview, conducted to the provincial government of DKI Jakarta and vertical greening system contractors. The results of this study pointed that the government and contractors most agree on the aesthetic benefits from the social aspect and the challenges of the initial investment from the cost aspect. The implementation of a vertical greening system at the flyover structure has been carried out in 14 different locations with the majority of the systems implemented were living walls.

Keywords
Vertical Greening System, Flyover Structure, DKI Jakarta, Benefits and Challenges, Existing Conditions.

1. Introduction
DKI Jakarta is an urban area with an area of 66.233 ha (Governor of DKI Jakarta Province 2007) and had a population of 14.5 million in working hours (DKI Jakarta Provincial Government 2017 in Hidayati 2019), so the population density reached 219 people/ha. Therefore, according to SNI 03-1733-2004 (National Standards Agency 2004), DKI Jakarta is an area with a high population density during working hours.

The high concentration of population caused gradual changes in green open spaces into high-rise buildings and roads (Elgizawy 2016). These changes occurred in DKI Jakarta along with an increased greenhouse gas emissions from motorized vehicles, where the average CO_2 emission was 6955.12 thousand tons from 2010 to 2017 (DKI Jakarta Provincial Environmental Agency 2018). As a result, an urban heat island phenomenon appeared and created microclimate changes where the temperature in the city was very high and increases dramatically to the city center, densely populated areas and industrial areas (Bahi et al. 2016). The urban heat island effect occurred in several locations in DKI Jakarta such as around Tanjung Priok, Jagorawi Toll Road, Cempaka Putih, Kemayoran, Jatinegara, Gatot Subroto, Duren Sawit, and so on (Prasasti et al. 2015).

Efforts to improve the local microclimate and mitigate the intensity of the urban heat island phenomenon could be carried out through the implementation of vertical greening system (Afshari 2017). The vertical greening system was considered as one of the most viable greening options because it did not require additional space and easily integrated into new or existing construction (Feitosa and Wilkinson 2018). In DKI Jakarta, the implementation of vertical greening system to deal with the urban heat island phenomenon has begun and has been implemented to flyover structures in several locations, such as Kalibata and Karet. Generally, the implementation of vertical greening systems was hindered by factors of cost, maintenance, sustainability, complexity, and vulnerability (Bustami et al. 2018, Riley

2017). In DKI Jakarta itself, the implementation faced several obstacles such as suboptimal maintenance (Prayoga 2019) and vandalism of supporting facilities (Andry and Anas 2020). The obstacles that occurred caused the vertical greening system unable to function optimally. Research conducted by Rasyidi et al. (2020) showed that DKI Jakarta continued to experience an increase in temperature in the period from 1996 to 2019, reached the highest temperature of >41 $^\circ$C in 2019.

Therefore, this study of vertical greening system implementation at the flyover structure in DKI Jakarta was carried out to become a new source of knowledge in increasing the implementation of the vertical greening system for the DKI Jakarta Provincial Government and contractors of the vertical greening system. This study aimed to identify the benefits and challenges of implementing a vertical greening system at the flyover structures in DKI Jakarta based on the perspective of the government and contractors as well as analyzed the existing conditions of implemented vertical greening system at the flyover structures in DKI Jakarta.

2. Literature Review

2.1 Flyover Structure

The flyover structure is a road that is built not on a plot with other roads with the aim of avoiding conflicts at intersections, traffic jams, and also increasing traffic safety and efficiency (Ramadhan and Rahmadini 2012). Its construction allowed mass to pass over hindrances without blocking the road beneath (Kumar et al. 2017).

Various literature (Directorate of Bridges and Directorate General of Highways 2020, Ramadhan and Rahmadini 2012) explained that the structural components of flyovers can be divided into superstructure and substructures. The superstructure consisted of components in the form of plates, primary girders, and secondary girders that function to drain dead loads, additional dead loads, live loads, and other loads downward. The substructure consisted of columns, pile caps, and foundation piles to transfer the load from the superstructure to the ground. Columns can be made from masonry, steel, or concrete to form single, massive pillars, or portals.

2.2 Vertical Greening System

Vertical greening system is a term used for all kind of green wall (Shafiee et al. 2020) and generally divided into green facades and living walls (Manso and Castro-Gomes 2015). A green facade refers to a ground-based greening system that relies on natural soil, while a living wall is a wall-based greening system that includes direct installation to walls and not connected to natural soil (Medl et al. 2017). Manso and Castro-Gomes (2015) classified each system into two categories: green facade systems had direct and indirect greening categories, while living wall systems had continuous and modular categories.

Each category can be identified based on the components used. The components of the green facade system in the direct greening category were irrigation (optional) and vegetation, while the indirect greening category used a structural framework (nets, cables, trellises, or grids), irrigation (optional), and vegetation (Medl et al 2017). In contrast to that, living wall systems have more complex components where the continuous category used structural frames, base panels, fabric layers, drainage, waterproofing membranes, irrigation systems, and vegetation. On the other hand, the modular living wall system used components in the form of structural structures, modular components (bags, planter boxes, or trays), substrates, drainage, waterproofing membranes, irrigation systems, and vegetation (Medl et al 2017).

Vertical greening system is generally implemented to the walls or facades of buildings, interiors and exteriors. However, there were also systems implemented to building columns, including flyover columns (Fauzi 2012). In its implementation, the vertical greening system went through several stages consisting of preparation, design and planning, installation, and maintenance (Fauzi 2012). The preparation stage consisted of project technical, administrative, and legal discussions to ensure smooth running of the project (Fauzi 2012). The design stage was intended to plan the characteristics of the vertical greening system and its benefits (Perini et al. 2013), drainage and irrigation plans, maintenance plans, practitioner role plans, and compliance with law (Australia Department of Environment and Primary Industries 2014). The civil and structural division was in charge of the design stage to carry out structural calculations, determine materials for construction, as well as consulting on budget plans, and making detail engineering designs (Fauzi 2012). The installation stage itself consisted of five phases, namely the design phase, setting, plant, hard material installation, and plant installation (GSky Plant Systems 2018). The maintenance stage was carried out on structural components and plants (Australia Department of Environment and Primary Industries 2014).

The implementation of vertical greening system brings various benefits that can be assessed from the building, environmental, and social aspects. The benefits in the building aspect were in the form of extending the life of the building by providing protection from wind, solar radiation, and rain (Haggag 2010) as well as saving on maintenance and replacement costs for building facade components because the vertical greening system was able to limit diurnal fluctuations of building facade temperature (Wong et al. 2010a). From an environmental point of view, the implementation of vertical greening system helped reduce air pollution by taking carbon dioxide from the air and replacing it with oxygen (Timur and Karaca 2013), reduced noise (Azkorra et al. 2015), and reduced the urban heat island effect by converting solar radiation into latent heat through the process of evapotranspiration, which was the transfer of water from plants to the atmosphere in the form of steam (Chen et al. 2013). The benefits of its implementation to social aspects were expressed by Meral et al. (2018), how positively people evaluate the visual parameters of living walls, and by Kosorić et al. (2019), that the implementation increased sustainability and enriched social life by encouraging social interaction.

Along with the benefits, challenges also arise in implementing a vertical greening system. The initial capital investment costs for exterior living wall systems were high compared to other exterior cladding systems (Perini et al. 2011) and maintenance costs could reach 8.5% (Perini and Rosasco 2013) or even 15% (Mathew and Salot 2014) of the living wall installation cost. Apart from the cost aspect, challenges also arise from the maintenance aspect. Equipment for maintenance access, such as lifts or stairs, should be budgeted and planned for storage, and maintenance training should also be provided for technicians (GSky Plant Systems 2018). Irrigation maintenance was also a challenge because over-watering could lead to plant death (Riley 2017). Another challenge came from the design aspect, where the design of the vertical greening system that was applied had to consider climatic and environmental factors such as temperature, humidity, wind, and orientation (Hopkins and Goodwin 2011) so that they can survive in the place they live in. Wong et al. (2010b) pointed that knowledge and awareness of the community, contractors, and the government was also a challenge in vertical greening system implementation. Lack of technical knowledge about vertical greening system led to uncertainty regarding related matters, such as design, installation, and maintenance requirements. Lack of awareness of the benefits and performance of a vertical greening system led to fear in implementing a vertical greening system.

3. Methods

3.1 Questionnaire Survey

Identification of the benefits and challenges of implementing vertical greening systems at the flyover structures in DKI Jakarta based on the perspective of the government and contractors was carried out using a quantitative approach in the form of surveys, using questionnaires as the research instrument. The questionnaires used a graded approval scale from 1 (strongly disagree) to 5 (strongly agree). The research variables used are independent variables with a total of 7 benefit indicators and 10 challenge indicators. The research sample was taken purposively with a target of 30 respondents from the DKI Jakarta Provincial Government and vertical greening system contractors with at least 3 years of work experience and have been or are currently working on a vertical greening system project.

Data collection began with the validation of variables and instruments by experts, pilot survey to prospective respondents, and then research questionnaire data to respondents. The validity of the data was assessed by testing the validity and reliability of the instrument. Data analysis was carried out quantitatively based on the results of descriptive statistical tests and inferential statistical tests. Descriptive statistical tests were carried out using the central tendency, namely mean, median, and mode along with the presentation of the data. Inferential statistical tests were carried out by testing normality, homogeneity, hypotheses, and correlations. The validity of the data and inferential statistics were tested with the help of the Statistical Package for Social Science (SPSS) computer software.

3.2 Interview Survey

Analysis of the existing condition of vertical greening system implementation at the flyover structures in DKI Jakarta was carried out with a qualitative approach in the form of surveys, using interviews as the research instrument. The research variables used were independent variables with a total of 36 existing condition indicators. The research sample was taken purposively, from the DKI Jakarta Provincial Government and vertical greening system contractors with a minimum of 8 years of work experience and have been or are currently working on a vertical greening system project.

Data collection began with the validation of variables and instruments by experts, then started collecting research interview data. The validity of the data was assessed by data triangulation, member checking, and auditing. Data analysis was carried out qualitatively with the stages of data reduction, data presentation, and data verification.

4. Data Collection

Participants in the questionnaire survey to identify the benefits and challenges consisted of experts for validation, pilot survey respondents, and questionnaire respondents. There are 3 experts consisting of 2 people from the government (DKI Jakarta Provincial Parks and Forest Agency) and 1 person from the contractor. The pilot survey respondents were 10 people, consisting of 7 people from the government and 3 people from contractors. The respondents to the questionnaire to identify the benefits and challenges were 43 people, with 3 of them having the exact same entries and 5 of them not meeting the criteria for work experience. Thus, the valid respondents for the benefits and challenges questionnaire were 35 people, consisting of 18 people from the government and 17 from contractors.

There are fewer participants in the interview survey, consisting of experts for validation and interviewees. The experts in the interview survey are the same as the questionnaire survey experts for validation, as well as concurrently serving as interviewees. Details of occupation and work experience from experts as well as interviewees can be seen in Figure 1, as from pilot survey respondents in Figure 2, and from questionnaire respondents in Figure 3.

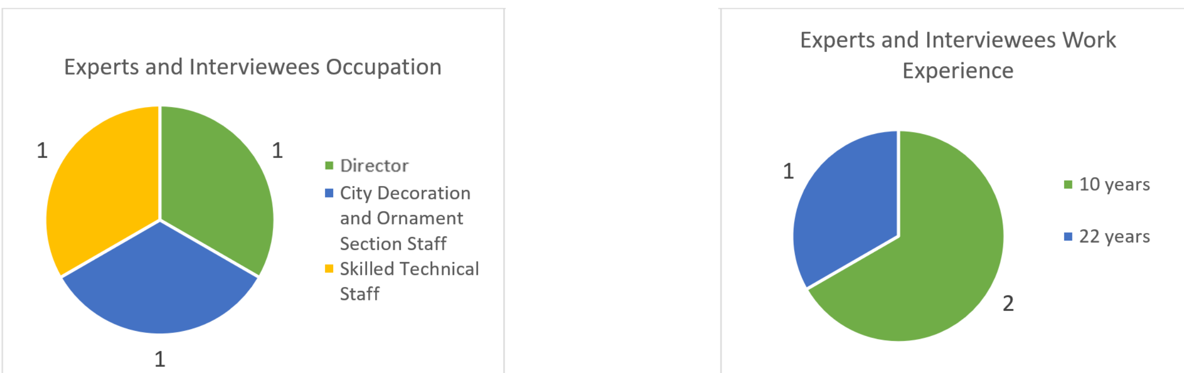
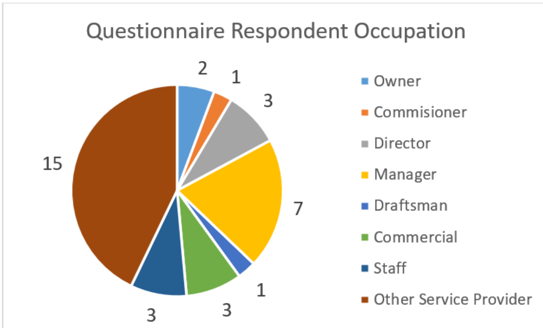


Figure 1. Occupation and Work Experience Distribution of Experts and Interviewees

Figure 2. Occupation and Work Experience Distribution of Pilot Survey Respondents



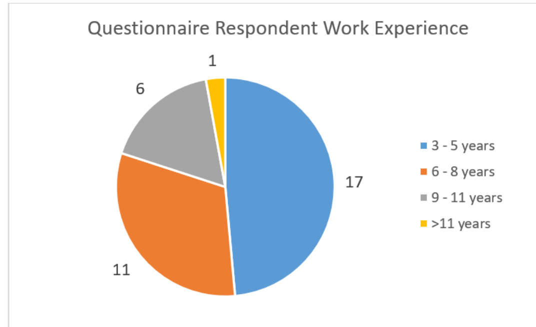


Figure 3. Occupation and Work Experience Distribution of Questionnaire Respondents

5. Results

5.1 Benefits and Challenges of Vertical Greening System Implementation

The results of the data collection on the validation of variables and instruments as well as the pilot survey showed that there was no need for any changes to the variables or research instruments for the research questionnaire. Data processing for the research questionnaire began with assessing the validity of the data through testing the validity and reliability of the instrument. The results of the validity test showed that all of the benefit indicators were valid, while 3 out of 10 challenge indicators were invalid. The invalid indicators were removed and not analyzed further. The invalidity of the indicator was caused by the extreme responses of respondents, there was a very low and very high likert scale value in one entry. The test was continued with the reliability test and the results showed that the benefit questionnaire had moderate reliability, while the challenge questionnaire had high reliability.

After validity of the data tests, normality and homogeneity tests were carried out on the research questionnaires from the respondents. The normality test result of the benefits questionnaire and the challenge questionnaire showed that the contents of the questionnaire were normally distributed so that hypothesis testing could be performed parametrically using a one-sample T-test. The homogeneity test of the benefit questionnaire and the challenge questionnaire showed that the contents of the questionnaire had different data variances or heterogeneous data. The data becomes heterogeneous due to differences in understanding and experience of each respondent.

Data processing continued with descriptive statistical tests, data presentation, and analysis. The entries for each respondent with a value between 1 – 5 were added up for each indicator, then the maximum value is determined by multiplying the highest entry value (5) by the number of respondents. After that, the total value of all respondents for each indicator was divided by the maximum value and multiplied by 100% so that the percentage of approval from all respondents for each indicator was obtained. The percentage of approval obtained determined the class classification of respondents' approval of the related indicators. The approval class consisted of strongly disagree (0% – 20%), disagree (20% – 40%), neutral (40% – 60%), agree (60% – 80%), and strongly agree (80% – 100%). Details of the percentage of government and contractor respondents' approval of each indicator of the research questionnaire can be seen in Table 1.

Table 1. Resume Results of Research Questionnaires by Government and Contractor Respondents

Variable	Subvariable	Subsubvariable	Government Respondents		Contractor Respondents	
			Percentage	Class	Percentage	Class
Benefits	Building	Age	56.67%	Neutral	60.00%	Neutral
		Maintenance Cost	54.44%	Neutral	57.65%	Neutral
	Environmental	Air Pollution	96.67%	Strongly Agree	91.76%	Strongly Agree
		Noise	94.44%	Strongly Agree	77.65%	Agree
Benefits	Environmental	Urban Heat Island	95.56%	Strongly Agree	85.88%	Strongly Agree

Variable	Subvariable	Subsubvariable	Government Respondents		Contractor Respondents	
			Percentage	Class	Percentage	Class
	Social	Social Interaction	64.44%	Agree	61.18%	Agree
		Aesthetics	97.78%	Strongly Agree	92.94%	Strongly Agree
Challenges	Cost	Initial Investment	72.22%	Agree	67.06%	Agree
	Maintenance	Access	57.78%	Neutral	51.76%	Neutral
		Irrigation	37.78%	Disagree	40.00%	Disagree
	Design	Temperature	63.33%	Agree	48.24%	Neutral
		humidity	52.22%	Neutral	49.41%	Neutral
		Wind	51.11%	Neutral	48.24%	Neutral
		Orientation	45.56%	Neutral	52.94%	Neutral

Data processing continued with inferential statistical tests, namely hypothesis testing and correlation testing. Hypothesis testing one sample t-test was conducted to test the hypothesis that the DKI Jakarta Provincial Government and the contractors of the vertical greening system agree on the benefits and challenges of implementing a vertical greening system at the flyover structures in DKI Jakarta. The test results showed that the hypothesis was accepted for the benefits questionnaire, but rejected for the challenges questionnaire. The correlation test was intended to examine the relationship between the benefits and challenges variables, the test results showed that there was a significant and inverse correlation between the benefits and challenges variables.

5.2 Existing Conditions of Vertical Greening System Implementation

The results of data collection on the validation of variables and instruments indicated that there was no need for any changes to the variables or research instruments for research interviews. Existing condition variables that were discussed in the research interview consisted of subvariables of existing application, design of flyover structure columns, design of vertical greening systems, maintenance of vertical greening systems, challenges of implementation in DKI Jakarta, and improvement of implementation in DKI Jakarta.

The results of the interview regarding the existing condition revealed that vertical greening systems has been implemented at the flyover structures in DKI Jakarta, at least in 14 different locations with the system implemented were 3 continuous living walls, 10 modular living walls, and 1 indirect green facade. Interviews regarding the column design of the flyover structure revealed that all of the columns implemented by the vertical greening system used concrete material, single and massive column types, between 3 – 10 meters high, and had a circular or square cross section.

Continuing to design of vertical greenery system, the system implemented consisted of living walls and green facades that were built without a waterproof membrane or irrigation system, but used components that include light steel, galvanized or hollow pipes, angled iron, dynabolt, clamps, wire, wiremesh, trellises, pots, geotextile carpets, substrates, and plants. System durability varied, 4 – 5 years or 15 – 20 years with the hope of lasting forever. Maintenance was done 1 or 3-4 times in 1 week. The contractor performed maintenance on the irrigation system and fertilization, drainage, and plant growth only. On the other hand, the government carried out maintenance on drainage, safety systems, other structural elements, planting design, plant growth, and substrate.

The government and contractors have responded differently to the challenges of implementation in DKI Jakarta. The government stated that the implementation challenges came from aspects of cost, maintenance, and design complexity, while contractors stated that the challenges only came from the aspect of knowledge and awareness. This difference in responses also occurred in interviews regarding increasing implementation in DKI Jakarta, where the government stated that the provision of implementation guidelines could improve the implementation of vertical greening systems on flyover structures in DKI Jakarta, but the contractor stated that the procurement of implementation guidelines could not help improve the implementation.

Based on the results of interviews and analysis, it can be seen that the hypothesis regarding the existing conditions of vertical greening system implementation, which is has been implemented to the flyover structure in DKI Jakarta with the majority of types implemented being living walls, is correct. This is because the existing application has been carried out in 14 different locations and the details of the system implemented were 13 types of living walls and 1 type of green facade. The map of vertical greening system implementation on flyover structures in DKI Jakarta can be seen in Figure 4.

Figure 4. Map of Implementation Locations of Vertical Greening System on Flyover Structures in DKI Jakarta

6. Discussion

6.1 Benefits and Challenges of Vertical Greening System Implementation

On the building aspect, the implementation of a vertical greening system helps extend its life by protecting the structure from heat and rain, in line with the explanation from Haggag (2010). However, an implementation that does not pay attention to the structure can actually damage it, as described by Mir (2011) where plant roots could penetrate the foundation and sewer pipes and also remove the surface layer of the building. This implementation also increases the cost of maintaining the flyover because the previously empty column is now filled with plants and their supporting structures which must be maintained regularly (Australia Department of Environment and Primary Industries 2014, GSky Plant Systems 2018). Continuing to the implementation benefits from an environmental point of view, the reduction of air pollution is certain because of the presence of vegetation in a vertical greening system. Vegetation is able to act as a natural filter as explained by Timur and Karaca (2013). Noise reduction was also justified by respondents because plants absorb sound, as evidenced by Azkorra et al. (2015). Respondents also said that the reduction of the urban heat island effect was certain, Chen et al. (2013) indicated that this was transpired by the evapotranspiration process. The benefits of implementing the social aspect also received various responses. Social interaction received a response that the benefits are very likely to be realized, as evidenced by Kosorić et al. (2019), if the implementation of a vertical greening system on the flyover structure was combined with a place for community interaction. The implementation also improves the aesthetics of the column because that makes it look green and beautiful, but improper maintenance can actually damage its aesthetics. This positive evaluation of aesthetics is in line with research conducted Meral et al. (2018) and also White and Gatersleben (2011).

Responses to other benefits suggest that there are other health and environmental benefits. From a health perspective, the implementation of a vertical greening system at the flyover structure can reduce residents' stress and contribute to peace of mind. Studies conducted by Elsadek et al. (2019) and Lotfi et al. (2020) showed that just by looking at a vertical greening system, humans get health benefits both physiologically and psychologically. Another environmental benefit is that the implementation is able to form a new ecosystem for animals, Hop and Hiemstra (2013) and also Timur and Karaca (2013) explained that vertical greening systems were able to attract the attention of birds and insects as well as be their hiding places and nests.

Continuing the discussion on the challenges, in terms of costs, the initial investment in vertical greening systems is indeed high but relatively cheaper than other countries. This could be influenced by various variables such as the size of the project and the cost of the design team (Šuklje et al. 2013). Challenges from the maintenance aspect also received responses from interviewees. Whether or not it is difficult to access maintenance depends on the situation and conditions, so it must be planned from the start. Regarding irrigation, the use of automatic irrigation systems was highly emphasized because of its various benefits, such as saving labor and streamlining water use (Tribowo 2017). Challenges in the design aspect, namely the influence of temperature, humidity, wind, and orientation are not too much of a problem and can be handled by selecting the right plants for various field conditions. This is in line with the explanation from Riley (2017).

Other challenges raised by respondents were the activeness of unreliable contractors in looking for projects and the need to consider the media under the column. Soil media is needed as a place for plants to take root if the vertical greening system to be used was a direct green facade system (Bustami et al. 2018).

6.2 Existing Conditions of Vertical Greening System Implementation

Information from interviewees regarding the implementation of the existing vertical greening system at the flyover structures in DKI Jakarta where 13 of the 14 systems implemented were living walls can be due to the various advantages offered by living walls such as flexible and attractive designs (Manso and Castro-Gomes 2015). Regarding the design of the flyover structure column, the column material in the form of concrete was commonly used because of the various advantages it offers, such as being able to be cast to take the desired shape (Hassoun and Al-Manaseer 2015). The type and height of the column is in accordance with the explanation from the Directorate of Bridges & the Directorate General of Highways (2020), where single columns were 5-15 meters high, while massive columns were 5-25 meters high.

The design of all the vertical greening systems implemented were without a waterproof membrane because there was an air cavity between the vertical greening system and the building, or the building considered waterproof (Australia Department of Environment and Primary Industries 2014). In addition, the automatic irrigation system was also not used because it was too modern so that it will complicate maintenance. The durability of the implemented vertical greening system was for 4-5 years and then major repairs or updates were carried out, in line with the explanation of Perini et al. (2013) that for a continuous living wall system the durability could reach 10 years while the modular one could reach > 50 years. The maintenance of the vertical greening system that differs between the government and contractors can be caused by the different components used by the two parties. There may also be differences in maintenance between contractors depending on the policies implemented (GSky Plant Systems 2020; LiveWall 2019).

Information from interviewees regarding the challenges of implementation in DKI Jakarta where the government stated that the challenges came from aspects of cost, maintenance, and design while the contractor stated that the challenges came from aspects of knowledge and awareness which were entirely justified by various previous studies (Hopkins and Goodwin 2011, Mathew and Salot 2014, Perini and Rosasco 2013, Riley 2017, Wong et al. 2010b). A government interviewee explained that the cost aspect was a problem because of budget restrictions for vertical greening system at the flyovers during the pandemic, a lot of the budget was diverted to health matters. The maintenance aspect was a problem because frequently the plants start to wither, even die, so they need to be cared for in the nursery. The design aspect was a problem because the location of the vertical greening system was under the flyover so it did not get enough sunlight. On the other hand, the contractor interviewee explained that the knowledge and awareness aspect was a problem because the good intentions of everyone who played a role in implementing the vertical greening system were still considered lacking. Improved implementation in DKI Jakarta through the development of comprehensive implementation guidelines approved by the government and in line with the research results of Irga et al. (2017), but not so influential according to contractor interviewee because contractors had provided manuals or guidelines for their products.

7. Conclusion

7.1 Benefits and Challenges of Vertical Greening System Implementation

Based on the results of data collection, analysis, and discussions that have been carried out to identify the benefits and challenges of vertical greening system implementation at the flyover structures in DKI Jakarta, the following conclusions can be drawn:

- The most approved benefit aspect and the percentage of approval according to the government (G) and contractor (C) was the environmental aspect (94.44% (G), 85.10% (C)), followed by the social aspect (81.11% (G), 77.06% (C)), then the building aspect (55.56% (G), 58.82% (C)).
- The most agreed benefits and the percentage of approval according to the government (G) and contractors (C) was aesthetic benefits (97.78% (G), 92.94% (C)) from the social aspect.
- The most approved challenge aspect and the percentage according to the government (G) and contractor (C) was the cost aspect (72.22% (G); 67.06% (C)), followed by the design aspect (53.06% (G); 49.71% (C)), then maintenance aspect (47.78% (G); 45.88% (C)).
- The most agreed challenge and the percentage according to the government (G) and contractors (C) was the initial investment challenge (72.22% (G); 67.06% (C)) from the cost aspect.

7.2 Existing Conditions of Vertical Greening System Implementation

Results of data collection, analysis, and discussions on existing conditions of vertical greening system implementation at the flyover structures in DKI Jakarta lead the following conclusions:

- 13 out of 14 vertical greening systems that have been implemented at the flyovers in DKI Jakarta were living wall systems.
- Columns that were implemented with vertical greening systems were single or massive concrete columns with a circular or square cross section.
- The vertical greening system implemented was designed for 4-5 years and used components in the form of plants, substrate, drainage system, and supporting structures.
- Maintenance of the implemented vertical greening system was carried out 3-4x/week, performed on drainage, safety systems, other structural elements, planting design, plant growth, and substrate.
- The challenges of implementing a vertical greening system at the flyover structures in DKI Jakarta stem from aspects of cost, maintenance, design, as well as knowledge and awareness.
- Increasing the Implementation of vertical greening systems at the flyover structures in DKI Jakarta could be done by making comprehensive implementation guidelines, which discuss definitions, benefits, tangible evidence of benefits, technical guidelines for site analysis to maintenance, and case studies.

References

Afshari, A., A new model of urban cooling demand and heat island—application to vertical greenery systems (VGS), *Energy and Buildings*, vol. 157, pp. 204–217, 2017.

Andry and Anas, A., Taman Vertikal Cikini Diperbaiki, Available: http://www.beritajakarta.id/read/4308/taman-vertikal-cikini-diperbaiki#.X3csFWgzZPY, October 2, 2020.

Australia Department of Environment and Primary Industries, *Growing Green Guide: A guide to green roofs, walls and facades in Melbourne and Victoria, Australia*, Victorian Government Department of Environment and Primary Industries, Victoria, Australia, 2014.

Azkorra, Z., Pérez, G., Coma, J., Cabeza, L. F., Bures, S., Álvaro, J. E., Erkoreka, A. and Urrestarazu, M., Evaluation of green walls as a passive acoustic insulation system for buildings, *Applied Acoustics*, vol. 89, pp. 46–56, 2015.

Bahi, H., Rhinane, H., Bensalmia, A., Fehrenbach, U. and Scherer, D., Effects of urbanization and seasonal cycle on the surface urban heat island patterns in the coastal growing cities: A case study of Casablanca, Morocco, *Remote Sensing*, vol. 8, 2016.

Bustami, R. A., Belusko, M., Ward, J. and Beecham, S., Vertical greenery systems: A systematic review of research trends, *Building and Environment*, vol. 146, pp. 226–237, 2018.

Chen, Q., Li, B. and Liu, X., An experimental evaluation of the living wall system in hot and humid climate, *Energy and Buildings*, vol. 61, pp. 298–307, 2013.

Directorate of Bridges and Directorate General of Highways, Perencanaan Jembatan, Available: https://docplayer.info/145201857-Perencanaan-jembatan-direktorat-jembatan-direktorat-jenderal-bina-marga.html, August 27, 2020.

DKI Jakarta Provincial Environmental Agency, *Laporan Akhir Inventarisasi dan Penyusunan Profil Emisi Gas Rumah Kaca Provinsi DKI Jakarta*, 2018.

Elgizawy, E. M., The Effect of Green Facades in Landscape Ecology, *Procedia Environmental Sciences*, vol. 34, pp. 119–130, 2016.

Elsadek, M., Liu, B. and Lian, Z., Green façades: Their contribution to stress recovery and well-being in high-density cities, *Urban Forestry and Urban Greening*, vol. 46, 2019.

Fauzi, F., Perancangan Vertical Greenery di PT. Envirospace Consultant, Indonesia, Available: http://repository.ipb.ac.id/handle/123456789/60041, October 2012.

Feitosa, R. C. and Wilkinson, S. J, Attenuating heat stress through green roof and green wall retro fit, *Building and Environment*, vol. 140, pp. 11–22, 2018.

Governor of DKI Jakarta Province, *Keputusan Gubernur DKI Jakarta No. 171: Penataan, Penetapan Batas dan Luas Wilayah Kelurahan di Provinsi Daerah Khusus Ibukota Jakarta*, 2007.

GSky Plant Systems, *PRODUCTS CATALOG*, GSky Plant Systems, Inc., 2018.

GSky Plant Systems, Available: https://gsky.com/, Accessed on October 24, 2020.

Haggag, M. A., The use of green walls in sustainable urban context: With reference to Dubai, UAE, *WIT Transactions on Ecology and the Environment*, vol. 128, pp. 261–270, 2010.

Hassoun, M. N. and Al-Manaseer, A., *Structural Concrete Theory and Design*, 6th Edition, John Wiley & Sons, Inc., Hoboken, New Jersey, 2015.

Hidayati, I., Mobilitas Sirkuler Jabodetabek, Available: http://lipi.go.id/publikasi/mobilitas-sirkuler-jabodetabek/27075, January 3, 2019.

Hop, M. E. C. M. and Hiemstra, J. A., Contribution of Green Roofs and Green Walls to Ecosystem Services of Urban Green, *IInd IS on Woody Ornamentals of the Moderate Zone*, pp. 475–480, 2013.

Hopkins, G. and Goodwin, C., *Living Architecture: Green Roofs and Walls*, CSIRO PUBLISHING, Victoria, Australia, 2011.

Irga, P. J., Braun, J. T., Douglas, A. N. J., Pettit, T., Fujiwara, S., Burchett, M. D. and Torpy, F. R., The distribution of green walls and green roofs throughout Australia: Do policy instruments influence the frequency of projects?, *Urban Forestry and Urban Greening*, vol. 24, pp. 164–174, 2017.

Kosorić, V., Huang, H., Tablada, A., Lau, S. K. and Tan, H. T. W., Survey on the social acceptance of the productive façade concept integrating photovoltaic and farming systems in high-rise public housing blocks in Singapore, *Renewable and Sustainable Energy Reviews*, vol. 111, pp. 197–214, 2019.

Kumar, M. H. S., Binitha, K. S. and Balaji, K, Design of Flyover Transverse Vertically by Using Hydraulic Jack, *International Research Journal of Engineering and Technology (IRJET)*, vol. 04, pp. 1731–1737, 2017.

LiveWall. Operation Manual for outdoor structures, Available: https://livewall.com/technical/maintenance/, July 9, 2019.

Lotfi, Y. A., Refaat, M., El Attar, M. and Abdel Salam, A., Vertical gardens as a restorative tool in urban spaces of New Cairo, *Ain Shams Engineering Journal*, 2020.

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

Mathew, J. and Salot, A., Feasibility Study of Green Walls at the University of Illinois, Available: https://icap.sustainability.illinois.edu/files/projectupdate/2503/FinalGreenWall.docx, November 12, 2014.

Medl, A., Stangl, R. and Florineth, F, Vertical greening systems – A review on recent technologies and research advancement, *Building and Environment*, vol. 125, pp. 227–239, 2017.

Meral, A., Başaran, N., Yalçinalp, E., Doğan, E., Ak, M. K. and Eroğlu, E., A comparative approach to artificial and natural green walls according to ecological sustainability, *Sustainability (Switzerland)*, vol. 10, 2018.

Mir, M. A., Green Facades and Building Structures, Available: https://repository.tudelft.nl/islandora/object/uuid%3Af262c218-8801-4425-818f-08726dde5a6c, December 12, 2011.

National Standards Agency, *SNI 03-1733-2004: Tata cara perencanaan lingkungan perumahan di perkotaan*, 2004.

Perini, K., Ottelé, M., Haas, E. M. and Raiteri, R., Greening the building envelope, facade greening and living wall systems, *Open Journal of Ecology*, vol. 01, pp. 1–8, 2011.

Perini, K., Ottelé, M., Haas, E. M. and Raiteri, R., Vertical greening systems, a process tree for green façades and living walls, *Urban Ecosystems*, vol. 16, pp. 265–277, 2013.

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

Prasasti, I., Sari, N. M. and Febrianti, N., Analisis Perubahan Sebaran Pulau Panas Perkotaan (Urban Heat Island) di Wilayah DKI Jakarta dan Hubungannya dengan Perubahan Lahan, Kondisi Vegetasi dan Perkembangan Kawasan Terbangun Menggunakan Data Penginderaan Jauh, *Prosiding Pertemuan Ilmiah Tahunan XX 2015*, pp. 383–391, 2015.

Prayoga, F., Taman Vertikal Tugu Tani yang Kembali Tampak Tak Terurus, Available: https://megapolitan.okezone.com/read/2019/07/25/338/2083357/taman-vertikal-tugu-tani-yang-kembali-tampak-tak-terurus, July 25, 2019.

Ramadhan, D. I. and Rahmadini, H., Analisis Perbandingan Biaya Konstruksi antara Box Girder dan PC-I Girder pada Proyek Pembangunan Jalan Layang Non Tol Antasari Blok-M (STA. 2+336 - 2+376), Available: http://digilib.polban.ac.id/gdl.php?mod=browse&op=read&id=jbptppolban-gdl-deainsanir-3405, November 28, 2012.

Rasyidi, E. S., Sandi, R. and Buraerah, M. F., Monitoring Perubahan Suhu Ibu Kota Negara Tahun 1993-2019 Menggunakan Citra Satelit Landsat, *Jurnal Ilmiah Ecosystem*, vol. 20, pp. 50-58, 2020.

Riley, B., The state of the art of living walls: Lessons learned, *Building and Environment*, vol. 114, pp. 219–232, 2017.

Shafiee, E., Faizi, M., Yazdanfar, S. A. and Khanmohammadi, M. A., Assessment of the effect of living wall systems on the improvement of the urban heat island phenomenon, *Building and Environment*, vol. 181, 2020.

Šuklje, T. Ž., Medved, S. and Arkar, C., An Experimental Study on a Microclimatic Layer of a Bionic Façade Inspired by Vertical Greenery, *Journal of Bionic Engineering*, vol. 10, pp. 177–185, 2013.

Timur, O. B. and Karaca, E., *Vertical Gardens - Advances in Landscape Architecture Chapter 22*, IntechOpen Limited, London, United Kingdom, 2013.

Tribowo, R. I., *Perancangan Irigasi Tetes untuk Tanaman Hortikultura*, LIPI Press, Jakarta, Indonesia, 2017.

White, E. V. and Gatersleben, B., Greenery on residential buildings: Does it affect preferences and perceptions of beauty?, *Journal of Environmental Psychology*, vol. 31, pp. 89–98, 2011.

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

Wong, N. H., Tan, A. Y. K., Tan, P. Y., Sia, A. and Wong, N. C., Perception Studies of Vertical Greenery Systems in Singapore, *Journal of Urban Planning and Development*, vol. 136, pp. 330–338, 2010b.

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