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Research Article

Plant Species Selection for Vertical Garden Systems with Multi-Criteria Decision Making Techniques

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Abstract
Vertical gardens are alternative green spaces produced for urban open-green spaces. In this study, the importance of correct plant use is emphasized in order to ensure the sustainability of vertical garden systems, which have an important place for urban ecology. AHP-TOPSIS and susceptibility analysis methods were used to determine the correct plant species. In the study, Bornova Metro Station, located in Bornova district of İzmir province, was chosen as a sample application area. SWOT analysis was carried out in the sample area and metal-fence systems were determined as the application model, taking into account the environmental conditions, user profiles and application cost. Then, plant selection criteria were created for the AHP method, taking into account the properties of metal fence systems, Izmir climate norms and expert opinions on the subject. The plant species used in vertical gardens were determined by the literature review. By using the TOPSIS method, ten ideal species that can be used in the sample area were determined among these plants. Afterwards, sensitivity analysis was applied to evaluate the reliability of these rankings. Plants determined to start from the most ideal; Trachelospermum jasminoides, Tecomaria carpensis, Hedera helix, Solanum jasminoides, Jasminum officinale, Distictis buccinatoria, Hydrangea petiolaris, Lonicera japonica, Bougainvillea glabra, Vigna caracalla. With this study, it has been seen that multi-criteria decision-making methods can be used to decide on plant materials in the design stages of vertical garden systems.

Key Words
““AHP, SWOT analysis, TOPSIS, Sensitivity analysis, MCDM techniques, Vertical garden systems.”

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1. Introductıon

Urban population growth and structuring constitute the basis of the environmental problems of today's cities in the world and in our country. The urban population is increasing in parallel with the increasing migration, especially from rural areas to cities. Migration to urban areas brings with it excessive and unplanned construction, industrialization and the use of natural resources to meet energy needs (Demirarslan and Demirarslan, 2018). This situation destroys forest areas and global climate changes, increases the urban heat island effect, increases air, water and noise pollution, increases the concrete pile of cities and reduces open-green areas (Uchida et al., 2021). Against these negativities in the cities, the importance of alternative green areas to be created in urban areas is emerging.

Vertical garden systems are alternative green spaces created in urban areas, just like roof gardens (Goel et al., 2022). Vertical garden systems are an aesthetically important design integral element with their ecological contribution to today's modern architecture and cities, dating back to the Hanging Gardens of Babylon (Kahraman et al., 2018). Inspired by the plants that live on the rocks, on the vertical surfaces of trees and on various structures in nature, the concept of vertical garden has been integrated into urban life today by the French botanist Patrick Blanc (Gür and Erduran Nemutlu, 2021). These systems can basically be defined as systems created by integrating plant material into the vertical surfaces of structures by means of various growing media or climbing wires (Bagheri Moghaddam et al., 2022).

Vertical gardens are systems with different application methods in themselves. Systems created using felt, modular panel systems, hydroponic systems and metal fence systems, also known as living walls, are the application methods of vertical gardens (Pérez-Urretarazu, 2021). Systems created using felt are systems where plant material is grown in pockets made of felt. In this system, there are cultivation pockets that contain soil on the felt ground plane and are also formed from felt. In systems created using felt, the water holding capacity of the felt material is used at the maximum level (Gür and Kahraman, 2022). Modular-panel systems are systems created in panels and with pots containing soil in modular form. In these systems, drip irrigation method is generally used. In most of the modular-panel system applications, there is an extra water collection reservoir in the system structure for the discharge and reuse of rain water and excess irrigation water (Çelik et al., 2015). Hydroponic systems do not contain soil. In these systems, plant material is grown in containers containing a water-plant nutrient solution. Hydroponic systems require more careful maintenance than other application methods (Salas et al., 2010). Metal-fence systems are traditional systems in which climbing plant species are placed directly in the soil or in pots and then wrapped in metal fencing or wire. These systems are generally used for curtaining or covering outdoor spaces, balconies, courtyards and similar spaces. In addition, the application costs of metal fence systems are also suitable compared to other application methods (Price et al., 2015).

Before applying vertical garden systems, various factors such as the suitability of the building surface, environmental and climatic factors, and user profile should be carefully evaluated. In particular, a more accurate decision-making process is created by using scientific methods based on numerical data in determining the application methods and the plant material to be used in the design, and the sustainability and functionality of the systems are placed on more solid foundations (Hosseini et al., 2021). Decision-making problems arise when there are disagreements on different issues at different stages of our lives. Decision-making is the process of choosing one or more of the most suitable among various alternatives, depending on a general purpose and based on certain criteria. In this process, Multi-Criteria Decision Making (MCDM) methods, which are based on pairwise comparisons of certain criteria, help the process with numerical data in order to reach the most accurate decision (Durak et al., 2021).

In the literature, multi-criteria decision-making methods are used in many different areas and in various decision-making problems. Majumdar et al. (2010) used the Analytical Hierarchy Process (AHP) method under certain criteria to evaluate the quality of cotton fibers in their study. Then, using the Order of Preference Technique according to Ideal Solution Similarity (TOPSIS) method, the best and worst alternatives among these fibers were ranked. They repeated the study on two different yarn types and stated that both types were compatible in the order of alternatives. In their study, Supçiler and Cross (2011) stated that it is very important for a company to work with the right supplier in order to be successful throughout the business process. In the study, they used the AHP and TOPSIS methods to determine the most appropriate supplier for the solution of the problem by addressing the supplier selection problem. As a result of the methods, they ranked the alternatives from the most ideal to the most non-ideal and determined A2 as the most ideal supplier. Chen et al. (2012) stated in their study that the selection of the best starting pitchers in the Chinese Professional Baseball League is a multi-criteria decision making problem. In the study, AHP and TOPSIS methods were used as methods to solve the problem of determining the best shooter. As a result of the application of the methods, they stated that Ken Ray, Jim Magrane and Orlando Roman were among the top three shooters who started the Chinese Professional Baseball League in the 2010 season. Geyik et al. (2016) mentioned the importance of choosing the right publisher in order to reach high readership at low cost. They stated that this selection stage is a multi-criteria decision making problem. In their studies, they used AHP and TOPSIS methods to solve this problem. By consulting the expert opinions on the methods; has determined delivery time, cost, brand value and competence criteria as selection criteria. Alakas et al. (2019) stated in their studies that educating patients for the most urgent treatment is as important as correct and good treatment in accidents and diseases that occur in daily life. They stated that the problem that arises in order to provide the best service in this field is the problem of multi-criteria decision making. As a method, they used AHP, TOPSIS and VIKOR methods in their studies. As a result of AHP-TOPSIS methods, the best alternative is EMS; As a result of the AHP-VIKOR methods, EMS and DORSER revealed that one of the companies is the best alternative. Tukan et al. (2020) mentioned in their study that the number of shipyards where maintenance and repair works can be done in the state of Maluka is low and that although potential areas are abundant, many companies dock out of the state. In the study, they used AHP and TOPSIS methods to determine the right place where such shipyards can be established. As a result of the application of the methods, they stated that Dobo region is the priority region, Saumlaki region is the second priority region, and Tual region is the third priority region. When the literature is examined, it has been seen that MCDM methods can be used in different areas. Based on this, it has been concluded that MCDM methods can also be used to determine the most suitable plant material in vertical garden systems.

In this study, the problem of determining the plant material to be used to ensure the sustainability of vertical garden systems, which have an important place in the ecology and silhouette of the city, is discussed. It is aimed to list the most suitable alternatives that can be used in the application of the area determined as an example by making evaluations according to various criteria among 69 plant species alternatives that can be used in vertical garden systems. In the second part of the study, information is given about the study area, which has a potential vertical garden area, and why this area is used. At the same time, information about the methods used is given in this section. In the third part, SWOT analysis was carried out to determine the vertical garden application method for the problem that constitutes the purpose of the study. Then, the AHP method and TOPSIS method were used to determine the 10 most suitable plants among the alternatives. At the end of the data collection, the sensitivity analysis of the cases created by multiplying the criteria obtained in the AHP method with different coefficients in the TOPSIS method was performed. In the last part, the results obtained in the study were evaluated and various suggestions were made.

2. Material and Method

2.1 Material

The main material of this study is some plant species suitable for use in vertical garden systems. These plant species were determined as a result of the literature review including master's and doctoral theses, articles, symposium and congress papers written on vertical garden systems and stated to be used in vertical garden systems (Table 1).

Table 1. Some Plant Species Used in Vertical Garden Systems (Aygencel, 2011; Örnek, 2011; Timur and Karaca, 2013; Üçok, 2014; Bates, 2017; Phonpo and Saetiew, 2017; Kırıt, 2018; Karakoç, 2019; Chaipong, 2020)

Plant Species	Family
Aechmea fasciata Linn. Baker	*Bromeliaceae*
Aeschynanthus radicans Jack	*Gesneriaceae*
Alocasia sanderiana Bull.	*Araceae*
Aloe ciliaris Haw.	*Asphodelaceae*
Ampelopsis aconitifolia Bunge	*Bignoniaceae*
Anthurium crystallinum Linden & Andre.	*Araceae*
Asplenium nidus L.	*Aspleniaceae*
Asplenium adiantum- nigrum L.	*Aspleniaceae*
Asplenium thunbergi Belangeri	*Aspleniaceae*
Berberis thunbergii var. atropurpurea nana Chenault	*Berberidaceae*
Bougainvillea glabra Choisy	*Nyctaginaceae*
Caladium lindenii Vent.	*Araceae*
Calathea makoyana Nichols.	*Marantaceae*
Campsis radicans (L.) Bureau	*Bignoniaceae*
Cardinal climber (Ipomoea quamoclit L.)	*Convolvulaceae*

Table 1 (Continued). Some plant species used in vertical garden systems

Plant Species	Family
Cardiospermum halicacabum Linn.	*Sapindaceae*
Carex morrowii Boott.	*Cyperaceae*
Carex oshimensis Nakai	*Cyperaceae*
Carex testacea Sol. ex Boott	*Cyperaceae*
Cercestis mirabilis Bogner.	*Araceae*
Chlorophytum bichetii Backer.	*Asparagaceae*
Chlorophytum comosum L.	*Asparagaceae*
Cineraria maritima Linn.	*Asteraceae*
Cissus antarctica Vent.	*Vitaceae*
Clytostoma callistegioides Cham.	*Bignoniaceae*
Cuphea hyssopifolia Kunth.	*Lythraceae*
Dianella tasmanica var. variegata C. Pynaert	*Asphodelaceae*
Distictis buccinatoria A. H. Gentry	*Bignoniaceae*
Dracaena surculosa Lindl.	*Asparagaceae*
Echinodorus cordifolius (L.) Griseb.	*Alismataceae*
Euonymus japonicus Thunb. cv. ‘Microphyllus’ H.Jaeger	*Celastraceae*
Festuca glauca Vill.	*Poaceae*
Fittonia albivenis (Lindl. ex Veitch) Brummit	*Acanthaceae*
Gelsemium sempervirens L.	*Gelsemiaceae*
Geogenanthus undatus C. Koch & Linden.	*Commelinaceae*
Gladiolus italicus Mill.	*Iridaceae*
Hedera helix L.	*Araliaceae*
Holcus mollis L.	*Poaceae*
Hydrangea petiolaris Siebold & Zucc.	*Hydrangeaceae*
Isolepis cernua (Vahl) Roem. & Schult.	*Cyperaceae*
Jasminum officinale L.	*Oleaceae*
Lathyrus odoratus L.	*Fabaceae*
Liriope muscari (Decne.) L. H. Bailey	*Liliaceae*
Liriope spicata (Thunb.) Lour.	*Liliaceae*
Lonicera japonica Thunb.	*Caprifoliaceae*
Monstera karstenia num Hort.	*Araceae*
Nandina domestica Thunb.	*Berberidaceae*
Neoregelia carolinae (Beer) L.B. Sm.	*Bromeliaceae*

Table 1 (Continued). Some Plant Species Used in Vertical Garden Systems

Plant Species	Family
Nephrolepis exaltata (L.) Schott	*Nephrolepidaceae*
Ophiopogon jaburan (Kunth) Lodd.	*Asparagaceae*
Ophiopogon japonicus (L. f.) Ker Gawl.	*Asparagaceae*
Ophiopogon planiscapus Nakai	*Asparagaceae*
Pellionia repens (Lour.) Merr.	*Urticaceae*
Peperomia caperata Yunck.	*Piperaceae*
Peperomia obtusifolia (L.) A. Dietr.	*Piperaceae*
Philodendron erubescens K. Koch & Augustin.	*Araceae*
Pilea cadierei Gagnep.	*Urticaceae*
Pittosporum tobira var. nana (Thunb.) W.T. Aiton	*Pittosporaceae*
Plectranthus scutellarioides (L.) R.Br	*Lamiaceae*
Polypodium vulgare L.	*Polypodiaceae*
Scindapsus pictus Hassk.	*Araceae*
Scirpus cernuus Vahl.	*Cyperaceae*
Solanum jasminoides Paxt.	*Solanaceae*
Syngonium podophyllum Schott	*Araceae*
Tecomaria capensis Thunb.	*Bignoniaceae*
Thunbergia alata Bojer ex Sims	*Acanthaceae*
Thymus vulgaris L.	*Lamiaceae*
Trachelospermum jasminoides Lindl.	*Apocynaceae*
Vigna caracalla L. Verdc.	*Fabaceae*

The study was carried out at Bornova Metro Station, where 38º27'30.43'' north latitude and 27º12'44.74'' east longitude coincide (Google Earth Pro, 2021). The metro station is located in the Bornova district of İzmir province and is on the metro line of İzmir Metro AŞ, which is affiliated to the metropolitan municipality. Its height above sea level is 24 m. The study area is very close to Ege University on Ankara Street and also shares a common area with municipal buses and bus stops (Figure 1). Bornova district, where the station is located, is the 3rd district with the highest population in İzmir province and the district population is 445232 people (Tunç, 2021). The metro station and its surroundings have been chosen as a study area because it has a dense human and vehicle circulation, appeals to very different user profiles, and this area is limited in terms of green space, and contains a lot of potential areas for vertical gardening.

Figure 1. Study Area

2.2. Method

SWOT analysis was used to determine the vertical garden application method, which was determined to be used in the study and which could be applied in the sample area with various challenging environmental factors. Will be able to list the alternatives and reveal the difference during the determination of plant materials to be used in vertical garden design by using the application method and the constraints of the climate data determined after the SWOT analysis; AHP and TOPSIS methods including mathematical solutions were used. In addition, different scenarios were created with sensitivity analysis and plant alternatives were analyzed. The process followed in determining the plant material alternatives to be used in the vertical garden system is shown in Figure 2.

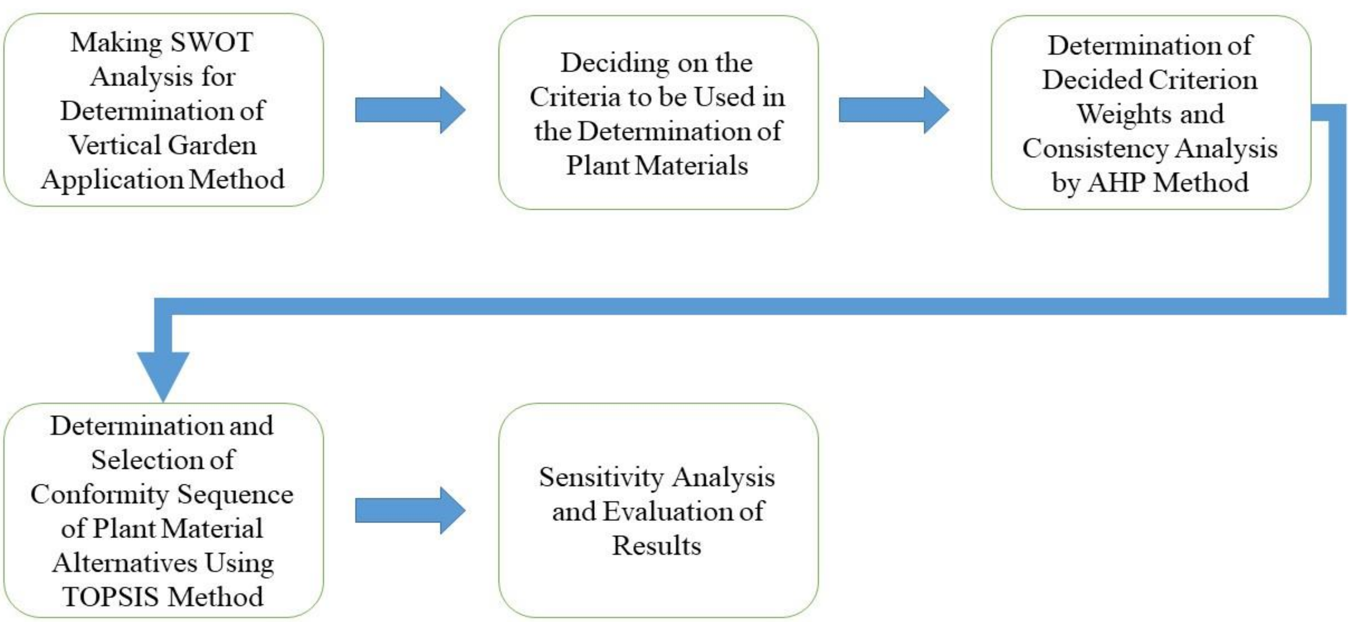

Figure 2. The Process of Determining The Plant Material

2.2.1. SWOT analysis

SWOT analysis is a method that enables the evaluation of strengths, weaknesses, threats and other variable factors that affect a particular issue. It is based on a systematic and accurate analysis of the subject in a broad framework (Helms & Nixon, 2010). This method can be used to determine the positive and negative variables in a certain area or environment, to overcome the difficulties in the focused target, to understand the problems encountered in the direction of the target and to guide the selection stages (Kumar et al., 2020).

2.2.2. AHP method

The AHP method is one of the multi-criteria decision-making methods (Eren and Gür, 2017). Developed by Thomas L. Saaty, this method is a mathematical model that facilitates making the necessary decisions during the selection stages (Hoque & Rohatgi, 2022). Developed by Thomas L. Saaty, this method is a mathematical model that facilitates making the necessary decisions during the selection stages (Hoque & Rohatgi, 2022). AHP consists of 5 steps (Hopfe et al., 2013; Xu, et al., 2022).

- Step 1: Determining the definition of the problem and creating the structure of the problem by the decision makers: In this step, the problem to be decided is handled, the criteria that are effective on the problem and in the decision-making process are determined. After the criteria are determined, a hierarchical structure is created.
- Step 2: Creating the pairwise comparison matrix: After the criteria are determined, pairwise comparison matrices are created and evaluated against each other. The structure of the pairwise comparison matrix is shown in Equation 1.

$$A = [a_{ij}] \begin{bmatrix} a_{11} & a_{12} & a_{13} & \cdots & a_{1n} \\ a_{21} & a_{22} & a_{23} & \cdots & a_{2n} \\ a_{31} & a_{32} & a_{33} & \cdots & a_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & a_{n3} & \cdots & a_{nn} \end{bmatrix} \quad (1)$$

While Saaty's 1-9 scale is used in this matrix structure, each criterion is evaluated according to another criterion. Table 2 shows the scale used during the assessment. This scale is used to indicate the dominance or importance of criteria in the comparison matrix.

Table 2. Saaty's Scale of 1-9 (Fawad et al., 2022).

Importance level	Definition	Explanation
1	Equally Important	Both factors are equally important.
3	Moderately Important	One factor is slightly more important than the other.
5	Strongly Important	One factor is strongly more important than the other.
7	Very Strongly Important	One factor is very strongly more important than the other.
9	Absolutely Important	One factor is absolutely strongly more important than the other.
2, 4, 6, 8	Intermediate Values	It is used when there are small differences between two factors.
Mutual values	If a value x is assigned when comparing i, j; The value to be assigned when comparing with i should be 1/x.	

The "i" and "j" values indicated in Table 2 represent the criteria. The "x" value indicates the superiority value given on a scale of 1-9 among the criteria. When the two criteria are compared, the "x" superiority value given is in a symmetrical structure and the division value of the 1/x part is written (Aydın et al., 2009).

- Step 3: Normalizing the pairwise comparison matrix: After evaluating the criteria, these values are normalized and the normalized matrix (a'_{ij}) is obtained. Equation 2 is used to obtain the normalized matrix.

$i = 1,2,3, \ldots, n$ ve $j = 1,2,3, \ldots, n$;

$$a'_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \quad (2)$$

According to Equation 2, the sum of the values of each column is found separately. Normalization is done by dividing the value in each column by the total value of the column it belongs to.

- Step 4: Determining the eigenvectors of the criteria: At this stage, the weights (w_i) of the criteria are calculated by averaging the row sums of the normalized matrices. This step is done with the help of Equation 3.

$i = 1,2,3, \ldots, n$; $j = 1,2,3, \ldots, n$;

$$w_i = \frac{\sum_{j=1}^{n} a'_{ij}}{n} \quad (3)$$

According to Equation 3, the value of each row is summed separately and divided by the number of criteria to find the weight of the criteria. The value "n" in the equation is equal to the number of criteria.

- Step 5: Performing the consistency analysis: Finally, the consistency ratio is calculated, which shows that the assessments are correct. It is desirable that this ratio be less than 0.1 (Malul & Bar-El, 2009). As a result of the analysis, a ratio greater than 0.1 indicates that there is inconsistency in the decision maker's criterion judgments.

2.2.3. TOPSIS method

TOPSIS method is a multi-criteria decision making method developed by Ching-Lai Hwang and Kwangsun Yoon in 1981. Attributes, goals and criteria are the basic principles of the method (Wang et al., 2022). The TOPSIS method consists of 6 different stages (Mao et al., 2018; Chakraborty, 2022).

3- As a result of the application of the AHP method, the selection criteria were determined, a hierarchical structure was created and the criteria weights were determined. TOPSIS method is a multi-criteria decision making method developed by Ching-Lai Hwang and Kwangsun Yoon in 1981. Attributes, goals and criteria are the basic principles of the method (Wang et al., 2022). The TOPSIS method consists of 6 different stages (Mao et al., 2018; Chakraborty, 2022).

- Step 1: Creating the decision matrix: The evaluation in the decision matrix is evaluated using certain score ranges. While preparing the decision matrix structure, the score ranges determined are scored according to each criterion, just like in the AHP method. The higher the importance, the higher the point value. An example of a decision matrix is shown in Table 3.

Table 3. Example of Decision Matrix (Demireli, 2010:104).

Alternatives	**Characteristics of Alternatives by Criteria**			
	k_1	k_2	k_3	k_n
a_1	k_{11}	k_{12}	k_{13}	k_{1n}
a_2	k_{21}	k_{22}	k_{32}	k_{2n}
a_3	k_{31}	k_{32}	k_{33}	k_{3n}
…	…	…	…	…
a_n	k_{n1}	k_{n2}	k_{n3}	k_{nn}

Table 3 (a_1, ..., a_n) refers to the alternatives listed one after the other. In addition, the expressions shown as (k_1, ..., k_n) express the evaluation criteria. Again, the values expressed as (k_{11}, ..., k_{nn}) in Table 3 are the evaluation scores of the alternatives' criteria characteristics.

- Step 2: Normalization of the decision matrix: After the decision matrix structure, the standard decision matrix is created in this step. Normalization is performed on the standard decision matrix. Equation 4 is used for this operation.

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} a_{ij}^2}}, \quad i = 1,2,\dots.m\,;\, j = 1,2\,\dots..n \tag{4}$$

According to Equation 4, the square root of the sum of the squares of the scores of the criteria in the decision matrix is taken, and the normalization of the matrix is performed.

- Step 3: Creating a weighted standard decision matrix: The standard decision matrix is converted to a weighted standard decision matrix. At this stage, the criteria weight values (w_{ij}) determined in the AHP method are multiplied with the values in the column of the standard decision matrix. With the realization of this process, a new matrix structure (v_{ij}) is formed.
- Step 4: Determination of ideal points: Negative ideal (A-) and positive ideal solution (A*) points are created using the weighted standard decision matrix structure. Equation 5 and Equation 6 are used for this operation.

$$A^* = \{(\max \mathrm{i}\ v_{ij}\ |j \in J), (\min i\ v_{ij}\ |j \in J^\iota)\}, A^* = \{v_1^*, v_2^*, \dots, v_n^*\} \tag{5}$$

$$A^- = \{(\min i\ v_{ij}\ |j \in J), (\max i\ v_{ij}\ |j \in J^\iota)\}, A^- = \{v_1^-, v_2^-, \dots, v_n^-\} \tag{6}$$

J refers to the benefit (maximization) and J^- loss (minimization) values in the equations.

- Step 5: Calculating the maximum distance to the ideal point: In this step, the maximum distance to the ideal point is calculated using Equation 7 and Equation 8.

$$S_i^* = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^*)} \tag{7}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^-)} \tag{8}$$

- Step 6: Calculating the distance to the ideal point: In this step, which is the last step of the TOPSIS method, the relative proximity to the ideal solution is calculated and alternative plants are ranked. Equation 9 is used for this step.

$$C_i^* = \frac{s_i^-}{s_i^- + s_i^*}, \quad 0 \leq C_i^* \leq 1 \tag{9}$$

This value should be between 0-1 as stated in Equation 9. 0 means the absolute closeness of the decision point to the negative solution, and 1 represents the absolute closeness of the decision point to the positive solution.

2.2.4. Sensitivity analysis

Sensitivity analysis expresses how well the alternatives perform on each criterion. This method shows how the effects of changing the criteria one by one on the alternatives will be reflected in the result. Thus, it is seen how sensitive the ranking of alternatives is (Mathur & VanderWeele, 2019).

3. Results

In the first stage of the study, Bornova Metro Station, which is the study area, was examined and observed on site in order to make SWOT analysis. Afterwards, SWOT analysis was conducted to determine the vertical garden application method. The results of the SWOT analysis are shown in Table 4.

Table 4. SWOT Analysis for Potential Vertical Garden Application at Bornova Metro Station

SWOT Analysis	
Strengths	**Weaknesses**
-It is a public space. -It is an area with heavy pedestrian use. -Potential floors are available for vertical landscape applications due to the intensive use of reinforced concrete.	-It has intensive human use because it is a subway area. -There is heavy traffic around the area. -The area is located under the Bornova Viaduct.
Opportunities	**Threats**
-The area has 240 m^2 of potential vertical garden area. -Spatial air quality can be increased with vertical garden applications. -Noise pollution caused by subway line and heavy traffic can be reduced.	-Most of the potential surfaces intersect with rest areas reserved for metro passengers. -As the potential surfaces are in open areas, they intersect with the smoking areas of waiting passengers.

When the strong features of the field are evaluated; the fact that it is a public area and has extensive pedestrian use provides this area with important features in terms of gaining green space on vertical systems. In addition, having a dense reinforced concrete surface as a vertical plane means that it has a lot of potential for the application of vertical garden systems. Considering the weaknesses of the field; The fact that it is used extensively by people means that it weakens the area as well as gives it strong features. Thus, it cannot be ignored that possible vertical garden applications will be exposed to too many human use every other day. At this point, it shows how important it is to really prioritize the sustainability of vertical gardens to be implemented. The heavy traffic in the region causes the metro area to be exposed to high levels of dust and polluted air. In addition, the fact that the metro area is located under the Bornova Viaduct causes the hot air here to circulate between the reinforced concrete structures. When the opportunities of the field are evaluated; having a potential area of 240 m^2 means that a large-scale area, just like on the horizontal plane, is transformed into green areas with these systems. Dust and polluted air caused by heavy traffic can be absorbed by plants in vertical garden systems and spatial air quality can be increased. Thanks to the insulation properties of vertical garden systems (Ekren, 2017), traffic and human-induced noise in the area can be isolated to a certain extent. When the threats of the area are evaluated; the fact that most of the potential areas are in the areas where metro users are waiting and smoking means that they will be used by user profiles of different socio-cultural and socio-economic structures. Therefore, the sustainability of vertical gardening practices may be threatened by Vandalism. The fact that the implementation cost of vertical garden systems is relatively higher than horizontal planes (Ekren, 2017) reveals that Vandalism-induced damages cause much more financial loss during the repair phase. According to the SWOT analysis, the metal fence system, which is considered to be sustainable, durable, cheap and less damaged due to its use by people from different socio-cultural structures, high mobility, shielding and ease of application, was chosen as the application method for the potential area. Metal fence systems are systems in which plants are surrounded by metal fences from soil or pots. For this reason, the plant material to be used in metal fence systems should be ivy and climbing species (Feng and Hewage, 2014). When the climate norms of İzmir province are evaluated; It is seen that the average of the winter months is 9.8 ^{o}C. Considering this temperature average, it is not important that the plant materials that are thought to be used in vertical garden systems do not have high tolerance to temperatures below 0 and frost. However, it is important that the plants that are thought to be used in vertical garden systems have a high tolerance to hot weather, since the average temperature of the province is high, such as 21.21 ^{o}C, except for the winter months. The climate norms of İzmir province are shown in Table 5.

Table 5. Izmir Climate Norms (URL-1, 2022).

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Average Temperature (ºC)	8.7	9.5	11.6	15.8	20.7	25.3	27.8	27.5	23.6	18.8	14.2	10.4	17.8
Average Highest Temperature (ºC)	12.3	13.5	16.2	20.8	26	30.7	33.1	32.9	29.1	23.9	18.5	14	22.6
Average Lowest Temperature (ºC)	5.7	6.1	7.6	11.1	15.4	19.8	22.4	22.3	18.6	14.5	10.6	7.4	13.5
Average Sunbathing Time (Hours)	4.2	5.1	6.4	7.9	9.8	11.5	12.2	11.9	10.1	7.5	5.5	4.1	96.2
Average Rainy Days	12.7	10.8	9.2	7.9	5.3	2.2	0.5	0.5	2	5.4	8.8	12.8	78.1
Average Monthly Total Precipitation (mm)	136.1	102.3	75.6	46	31.3	11.6	4.1	5.7	15.8	44.6	93.7	144.3	711.1
Highest Temperature (ºC)	22.4	27	30.5	32.5	37.6	41.3	42.6	43	40.1	36	30.3	25.2	43
Lowest Temperature (ºC)	-8.2	-5.2	-3.8	0.6	4.3	9.5	15.4	11.5	10	3.5	2.9	-4.7	-8.2

Total Daily Peak Precipitation	Daily Fastest Wind	Highest Profit
29.06.2006 - 145.3 mm	29.03.1970 - 127.1 km/h	31.01.1945 - 32 cm

Metal-fence systems determined as vertical garden method by SWOT analysis and selection criteria for the 1st step of AHP method according to İzmir climate norms were determined. In determining the criteria, the opinions of four landscape architects aged between 35-50 who are experienced in vertical garden systems and their applications and an agricultural engineer experienced in vertical agriculture were taken. As a result, for the AHP method; "Climbing plant species", "Dust and air pollution resistance", "Leafy structure" and "Heat resistance" criteria were determined. The hierarchical structure of the determined criteria has been established and the hierarchical structure is indicated in Figure 3.

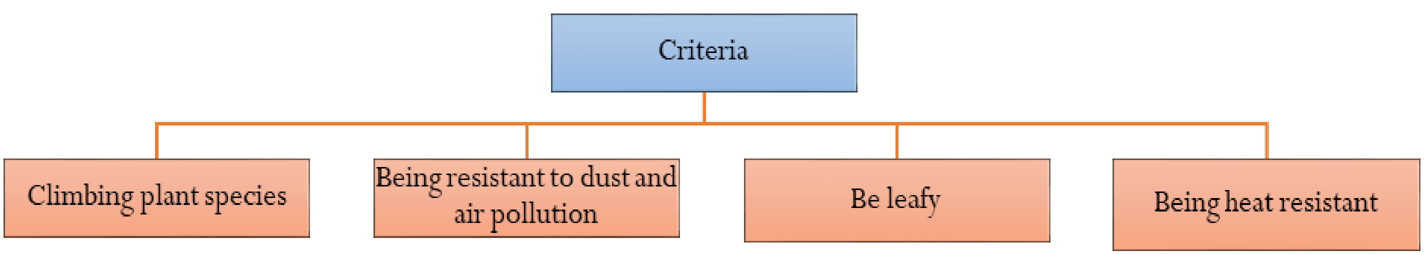

Figure 3. Hierarchical Structure of Criteria

After the criteria were determined and the hierarchical structure was created, the second step of the method was passed and the pairwise comparison matrix was created. In the dual decision matrix, the experts whose opinions were taken in determining the criteria were also asked to fill in this matrix structure. As a result, by taking the geometric mean of all the data, a pairwise comparison matrix was created according to Equation 1. The pairwise comparison matrix is indicated in Table 6.

Table 6. Pairwise Comparison Matrix

Criteria	A	B	C	D
A	1.00	9.00	5.00	3.00
B	0.11	1.00	0.25	0.33
C	0.20	4.00	1.00	0.50
D	0.33	3.00	2.00	1.00
Total	1.64	17.0	8.25	4.83

Climber plants species (A), Leafy (B), Be resistant to dust and air pollution (C), Be Heat-Resistant (D)

After the second step was completed, the values in Table 6 were normalized by proceeding to the third step of the AHP method. Normalization operations were performed according to Equation 2. The normalized pairwise comparison matrix is shown in Table 7.

Table 7. Normalized Matrix

Normalization	A	B	C	D
A	0.609756098	0.529411765	0.606060606	0.620689655
B	0.067073171	0.058823529	0.030303030	0.068965517
C	0.121951220	0.235294118	0.121212121	0.103448276
D	0.201219512	0.176470588	0.242424242	0.206896552

Climber plants species (A), Leafy (B), Be resistant to dust and air pollution (C), Be Heat-Resistant (D)

After the normalized matrix was created, the eigenvector weights of the criteria were calculated in the 4th step. Equation 3 is used to calculate the eigenvector weights of the criteria. The eigenvector weights of the criteria are given in Table 8.

Table 8. Eigenvector Weights of Criteria

Criteria	Criterion weights
Climber plants species	0.591479531
Leafy	0.056291312
Be resistant to dust and air pollution	0.145476434
Be Heat-Resistant	0.206752724

After the criterion weights were calculated, the last step of the method was passed and consistency analysis was performed. As a result of the analysis, it was determined that the consistency ratio was less than 0.1 (0.037113117), that is, the selection criteria were reasonable. After the selection criteria were weighted and consistency analysis was performed, the TOPSIS method was used.

In the decision matrix (Table 9) created in the 1st step of the TOPSIS method, the alternatives were scored between 1-10 on the basis of criteria. The reason for choosing this scoring range is to eliminate the processing overhead. Due to the large number of plants, Table 9, Table 10 and Table 11 are shown in abbreviated form. In other words, these three tables did not show all 69 plants as in Table 1. The structure of Table 9 is set as in Table 3.

Table 9. Decision Matrix Structure

Alternatives Plants	Criteria			
	Climber plants species	**Leafy**	**Be resistant to dust and air pollution**	**Be Heat-Resistant**
Aechmea fasciata Linn. Baker	1	2	3	8
Aeschynanthus radicans Jack	8	8	5	8
Alocasia sanderiana Bull.	1	1	2	8
Aloe ciliaris Haw.	5	1	5	7
Ampelopsis aconitifolia Bunge	9	5	4	6
Anthurium crystallinum Linden & Andre.	2	2	3	8
Asplenium nidus L.	1	5	4	7
Asplenium adiantum- nigrum L.	1	5	3	7
Asplenium thunbergi Belangeri	1	7	3	7
Berberis thunbergii var. atropurpurea nana Chenault	1	8	8	7

In the TOPSIS method, after the decision matrix structure, the standard decision matrix was created in the second step. Equation 4 was used while creating the standard decision matrix structure. The standard decision matrix structure is specified in Table 10.

Table 10. Standard Decision Matrix

	Climber plants species	**Leafy**	**Be resistant to dust and air pollution**	**Be Heat-Resistant**
Aechmea fasciata Linn. Baker	0.022021945	0.028733141	0.058565161	0.096030735
Aeschynanthus radicans Jack	0.176175558	0.097611798	0.090328672	0.096030735
Alocasia sanderiana Bull.	0.022021945	0.012201475	0.024751793	0.086894945
Aloe ciliaris Haw.	0.110109724	0.016143738	0.084455122	0.071162322
Ampelopsis aconitifolia Bunge	0.198197503	0.080718690	0.074023321	0.068554642
Anthurium crystallinum Linden & Andre.	0.044043890	0.023043371	0.053571429	0.091406189
Asplenium nidus L.	0.010009012	0.057608427	0.071428571	0.071162322
Asplenium adiantum-nigrum L.	0.010870850	0.061007374	0.047012936	0.066633434
Asplenium thunbergi Belangeri	0.022021945	0.070246294	0.037127689	0.066633434
Berberis thunbergii var. atropurpurea nana Chenault	0.022021945	0.068868343	0.099007171	0.066633434

In the third step, the standard decision matrix is transformed into a weighted standard decision matrix. For this, the weights obtained from the AHP method were used. Table 11 shows the weighted decision matrix.

Table 11. Weighted Normalized Decision Matrix

Weighted Normalized Decision Matrix				
Weights	0.591479531 **(A)**	0.056291312 **(B)**	0.145476434 **(C)**	0.206752724 **(D)**
Aechmea fasciata Linn. Baker	1.302552958	0.161742621	0.851985074	1.985461600
Aeschynanthus radicans Jack	10.42042366	0.549469618	1.314069305	1.985461600
Alocasia sanderiana Bull.	1.302552958	0.068683702	0.360080256	1.796576659
Aloe ciliaris Haw.	6.512764788	0.090875219	1.228622997	1.471300391
Ampelopsis aconitifolia Bunge	11.72297662	0.454376096	1.076864877	1.417385892
Anthurium crystallinum Linden & Andre.	2.605105915	0.129714159	0.779338039	1.889847856
Asplenium nidus L.	0.592012582	0.324285397	1.039117386	1.471300391
Asplenium adiantum- nigrum L.	0.642988506	0.343418511	0.683927422	1.377664394
Asplenium thunbergi Belangeri	1.302552958	0.395425604	0.540120383	1.377664394
Berberis thunbergii var. atropurpurea nana Chenault	1.302552958	0.387668939	1.440321022	1.377664394

Climber plants species (A), Leafy (B), Be resistant to dust and air pollution (C), Be Heat-Resistant (D)

Using the structure in Table 11, negative ideal and positive ideal solution points were created. In order to create the ideal points, the highest and lowest values in the normalized matrix of the evaluation factor in the decision matrix were determined. Equation 7 and Equation 8 were used while determining these values. These points are shown in Table 12.

Table 12. Ideal and Negative Ideal Solution Points

	Creating Ideal and Negative Ideal Solutions			
Ideal Solution	13.02552958	0.833670102	2.529110236	2.362309820
Negative Ideal Solution	0.543053297	0.068683702	0.360080256	1.261114621

The plants were ranked by calculating their relative closeness to the ideal solution, which is the last step of the TOPSIS method (Table 13). Equation 9 was used in this calculation process. The plants shown in Table 13 show, respectively, the 10 most ideal plants to be used for the potential area among the alternatives.

Table 13. Ranking of Plants.

Relative Proximity to The Ideal Solution	
Trachelospermum jasminoides Lindl.	0.999371670
Tecomaria capensis Thunb.	0.979890177
Hedera helix L.	0.958574796
Solanum jasminoides Paxt.	0.955526207
Jasminum officinale L.	0.939493990
Distictis buccinatoria A. H. Gentry	0.936984270
Hydrangea petiolaris Siebold & Zucc.	0.920083866
Lonicera japonica Thunb.	0.913415027
Bougainvillea glabra Choisy	0.910090244
Vigna caracalla L. Verdc.	0.888484376

After completing the steps of the TOPSIS method, the last stage of the study method was started with the determination of the most suitable 10 plant species for the vertical garden system to be applied in the sample area among the plant species alternatives. At this stage, sensitivity analysis was carried out. The method used by Hamurcu and Eren (2020) in their studies was used in the sensitivity analysis. Since the ranking of the alternatives in the TOPSIS method depends on the criterion weight coefficients, it has been analyzed whether the proportional changes in the criterion weights will cause a change in the ranking of the most ideal plant species. At this stage, 13 different scenarios were created. The first 12 scenarios; By using three different increase rates, 0.25, 0.50, 0.75, the criteria coefficients were changed according to these rates in each scenario. In the 13th scenario, the analysis was made considering that the criteria weights were not taken into account, that is, all criteria weights were 1 in the TOPSIS method. The 13 sensitivity analysis scenarios using the new criterion weights are given in Table 14.

Table 14. Sensitivity Analysis Scenarios

Scenarios	Criterion Weights	Coefficient of Change	New Criterion Weight
Scenario 1	0.591479531=A	0.591479531 x 1,25	0.73934941375
Scenario 2	0.056291312=B	0.056291312 x 1,25	0.07036414000
Scenario 3	0.145476434=C	0.145476434 x 1,25	0.18184554250
Scenario 4	0.206752724=D	0.206752724 x 1,25	0.25844090500
Scenario 5	0.591479531=A	0.591479531 x 1,50	0.88721929650
Scenario 6	0.056291312=B	0.056291312 x 1,50	0.08443696800
Scenario 7	0.145476434=C	0.145476434 x 1,50	0.21821465100
Scenario 8	0.206752724=D	0.206752724 x 1,50	0.31012908600
Scenario 9	0.591479531=A	0.591479531 x 1,75	1.03508917925
Scenario 10	0.056291312=B	0.056291312 x 1,75	0.09850979600
Scenario 11	0.145476434=C	0.145476434 x 1,75	0.25458375950
Scenario 12	0.206752724=D	0.206752724 x 1,75	0.36181726700
Scenario 13	0.591479531=A	Condition of All Criteria with Equal Coefficients	1
	0.056291312=B		1
	0.145476434=C		1
	0.206752724=D		1

As indicated in Table 14, the weighting coefficients of the criteria were increased by 0.25, 0.50 and 0.75, respectively, at each stage of the sensitivity analysis. In each scenario, only one criterion was chosen, where the weight coefficient increased with the specified values. In addition, in the 13th scenario, while the weighted decision matrix was created in the TOPSIS method, 1 was written for all criterion coefficients. As a result of the sensitivity analysis, the change in the rankings of the alternatives in the 13 scenarios is shown in Figure 4.

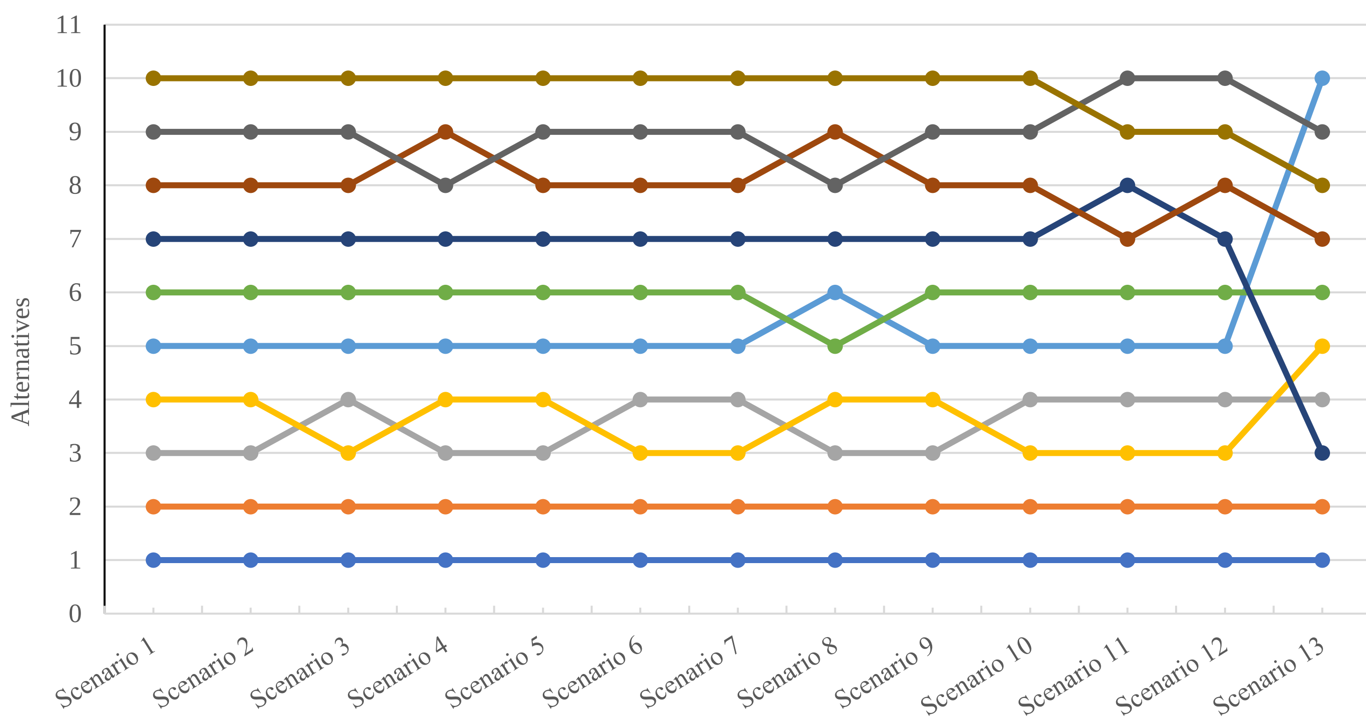

Figure 4. Changes in The Rankings of Alternatives Over 13 Scenarios

The results showed that in 12 of 13 scenarios, giving different weights to the criteria did not cause a significant change in the rankings of the alternatives. In the 13th scenario, the criteria weights being equal created changes in the ranking. Those who scored high in the decision matrix took their places in the changing order because they were multiplied by the ineffective element in the coefficients in this scenario. However, in scenario 13, the distances between preference rankings have increased and become more pronounced, thus affecting the results of the integrated use of AHP-TOPSIS. However, in the other 12 scenarios, there was satisfactory rank affinity and the proposed AHP-TOPSIS alternative rankings turned out to be reliable. Similar to this study, Gür (2021) used AHP and TOPSIS methods in an integrated way to determine the plant species that grow naturally in the Izmir region and can be used in vertical garden systems. In his study, he quantitatively determined that *Lavandula stoechas* L. plant is the most suitable species. Later, this plant proved the accuracy of the result obtained by testing its ability to grow in vertical garden systems. In this study, alternative plants were determined for a specific design area among the plants currently used in vertical garden systems. Therefore, this study is different from other similar studies; it differs in terms of choosing plants for design, using SWOT analysis as well as AHP and TOPSIS methods.

4. Conclusion

Unemployment has increased in rural areas as manpower has been replaced by industrialization and increased mechanization. Indirectly, in this case, people living in rural areas have started to migrate to cities in order to achieve a better income and quality of life. The desire of the increasing urban population to use natural resources, construction and development plans due to migration causes great damage to urban open-green areas. Sustainability and protection of open-green areas in urban areas is very important. It has gained importance to create alternative areas for the protection of open-green areas. Vertical garden systems are one of the alternative open green spaces created in urban areas. The correct use of plants in vertical garden systems is very important for the continuity and protection of urban ecology as well as providing aesthetic contributions. In the potential application area of Bornova Metro Station, which was chosen as a sample for the study, SWOT analysis was used to determine the vertical garden application method, taking into account the space-user relations and environmental conditions. As a result of the analyses made, it was determined that the most ideal application method for the potential area was the metal-fence system. As a result of the literature review, some plant species used in vertical garden systems were determined and listed. The vertical garden application method and the 10 most ideal plant species to be used in accordance with environmental conditions were determined using AHP and TOPSIS methods from 69 plant species. Starting from the ideal 10 plants determined as a result of the methods; *Trachelospermum jasminoides* Lindl. *Tecomaria capensis* Thunb., *Hedera helix* L., *Solanum jasminoides* Paxt., *Jasminum officinale* L., *Distictis buccinatoria* AH Gentry, *Hydrangea petiolaris* Siebold & Zucc., *Lonicera petiolaris* Siebold & Zucc. The plant species farthest from the ideal sequence is *Asplenium adiantum-nigrum* L. Then, after all procedures, sensitivity analysis was performed to measure the reliability of the results obtained from the AHP and TOPSIS methods. As a result of the sensitivity analysis, it was determined that the alternative rankings as a result of the AHP and TOPSIS methods were reliable. In this study, SWOT analysis, AHP and TOPSIS methods and sensitivity analysis were used to quantitatively determine plant material alternatives to be used in vertical garden design. At the same time, the study is the first to our knowledge in the landscape architecture literature in terms of using these four methods together in determining plant material for vertical garden systems. The use of multi-criteria decision-making methods in the field of plant selection and supply of plant nutrition products, in urban design stages, in rural and urban sustainable planning studies, in evaluating the suitability of natural plant species for landscape studies, will be useful in later studies and will contribute to the landscape architecture literature.

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