Title: EVALUATION OF THE SUSTAINABLITY OF VERTICAL GARDENS

Author Names: Parastou Ansari[1], Muhammed Ali Örnek[1]

1.Introduction-Objectives:

In order to reduce the environmental challenges caused by rapidly increasing urbanization and climate change, nowadays it has been proposed to give more place for nature in humans living spaces. Considering the restricted available spaces in the city centers, vertical gardens seem to be a potential solution by reducing the required space for growing plants. Although vertical gardens may have some benefits for today's modern life, considering the used materials and maintaining difficulties it seems that they are not sustainable as they seem. Continuous maintenance, irrigation difficulties, excessive use of water and chemical fertilizers, short life span of plants, increase in the constructed areas and the used plastic materials all lead to a raise in carbon footprint in urban areas. This study aims to provide a better perspective about sustainability of these systems by discussing the advantages and disadvantages for researchers and decision-makers in the area of urban planning and landscape architecture.

1.1 Literature Review:

- **Vertical Gardens:**

Vertical gardens increase the aesthetic value of urban areas. Also they have various benefits in terms of reducing the environmental impacts caused by increasing urbanization and climate change. The first sample applications go back to 2500 years ago in the hanging gardens of Babylon. Similar applications are also found in the Roman Empire (Palermo & Turco, 2020). These green systems can be used for urban agriculture by selecting edible plants and providing the necessary conditions. Covering building facades with these structures can decrease the used energy by providing a thermal insulation (Luskin center, 2018). They also can help to reduce urban heat island effect. Vertical gardens can also be used as an aesthetic solution to reduce noise pollution indoors or along roadsides, since plants prevent the reflection of sound waves and provide acoustic protection (Chew & Conejos, 2016). Additionally, vertical gardens as part of sustainable urban drainage system, filter rainwater, reduce runoff and assist urban rainwater management (Lau & Mah, 2018). They improve air quality by absorbing dust, toxins and carbon dioxide and emitting oxygen (Helzel, 2012; Kalay, 2019). Along with increasing biodiversity (Brisco, 2020), they improve people's quality of life science they provide an aesthetic green space for urban residents by occupying the least amount of space, especially in city centers where buildings are concentrated. Various systems can be used based on the implementation

objectives of vertical gardens like hydroponic, aquaponics, aeroponic, soil system, planting by using felt, hanging system, fence system and biofitration system.

Figure1: Various vertical garden systems.

- **Sustainability**

Sustainability means meeting our own needs without hindering the ability of future generations to meet their own needs. Sustainability is not just environmentalism. We also find concerns for social equity and economic development in most definitions of sustainability (Office of Sustainability University of Alberta, 2020; Patarlageanu, 2020). As in every application, it is necessary to pay attention to the concept of sustainability in the design, application, use and maintenance stages of vertical gardens.

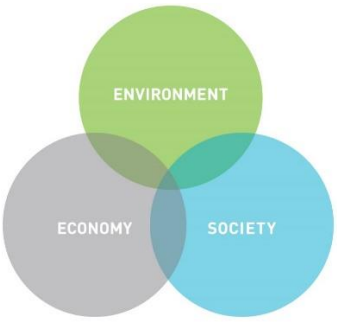

Figure2: Diagram of Sustainability (Office of Sustainability University of Alberta, 2020).

2. Materials and Methods:

In this research, we reviewed the literature on vertical gardens and sustainability and analyzed it systematically to extract the parameters which affect the carbon footprint of applications from early design to maintaining process. The findings have been collected in a selection pool and classified in

terms of their role, importance, and requirements for sustainability. The classified parameters rated as required and optional with points to guide decision-makers to evaluate a vertical garden design proposal or existing application.

The gathered information indicated that different aspects of vertical gardens can be categorized under eight topics: (1) site context, (2) plant species and design, (3) water and fertilizer usage, (4) implementation system and process, (5) applied technologies and energy efficiency, (6) material selection (7) user's utility and (8) maintenance. For each topic, measurable principles and criteria are identified in tables that can be pointed regarding their performance in order to identify necessary requirements for reaching sustainability. The obtained approach can be used for evaluating the sustainability of vertical gardens.

In this study, in the scoring system which is designed for the evaluation of vertical gardens, there are 12 necessary and 30 optional scoring criteria under 8 categories mentioned above. In order to consider a vertical gardens as sustainable, according to this designed evaluation system, it is necessary to meet the required criteria. The absence or insufficiency of the evaluated criterion does not earn points for the vertical gardens. While the weakness of the criterion gives 1 point, the good condition gives 2 points and the successful situation gives 3 points. All scoring factors are considered optional; however, a project must earn a certain number of points in order to be recognized as sustainable according to this evaluation system. While a total of 90 points is found in this evaluation system, a vertical garden with 30 points will be considered sustainable.

3.Findings:

3.1 Site Context

The location of implementations has a significant effect in sustainability of vertical gardens. It has been proved that planets close to the high-traffic roads contain 8-11 times more heavy metals than plants far from roads (Ndiokwere, 1984). Air pollution and heavy metal content in plants adversely affects plant ecology and leaf quality (Elkoca, 2003; Nuhoğlu, 1993). Therefore, it is necessary that vertical gardens be kept away from heavy-traffic roads and low air quality places (Khalid et al., 2018).

The effect of sound waves on the growth of plants varies according to the frequency and amplitude of the waves and their distance from the sound source. Sound waves with appropriate frequencies and pressure levels can significantly increase the division of callus cells and cell wall fluidity in plants, also considerably increase the activity of protective enzymes and endogenous hormones (Hassanian et al., 2014). However, plants close to heavy traffic roads are constantly exposed to high noises.

Also, if there is an existing historical building or a spiritual memory in the place where the vertical garden will be applied, it should be protected without any damages. In this regard, it would be useful to consult official sources and contact local residents to discover the historical value of the implementation location. Similarly, If the application area is the habitat of a plant or animal in danger of extinction, its location needs to be changed. Pre-configured areas or abandoned brownfields should be preferred in site selection to avoid damaging existing habitats (Green Business Certification Inc, 2014). Easy access to vertical gardens positively affects people choosing to visit there. In this context, the presence of public transportation facilities such as bus, metro, train and taxi to the point where the vertical garden is located is an appropriate design criterion in site selection and increases access to the vertical garden (Soydan, 2020). These criteria and given points are demonstrated in the given table below.

Table 1: Site context factors affecting the sustainability of the vertical garden.

NO	**1:Site Context**	Points
1	Distance to heavy traffic roads (Ndiokwere, 1984; Khalid et al, 2018; Elkoca, 2003; Nuhoğlu, 1993)	Required
2	Site air quality (Ndiokwere, 1984; Khalid et al, 2018; Elkoca, 2003; Nuhoğlu, 1993)	0-3
3	Site noise level (Hassanian, 2014)	0-3
4	Protect cultural and historical buildings and memories (Green Business Certification Inc, 2014)	Required
5	Protect existing habitat (Green Business Certification Inc, 2014)	Required
6	Accessibility (Soydan, 2020)	0-3

3.2 Plant Species and Design

Another important concern in sustainability of vertical gardens is plant species and design. Although vertical garden plants are always associated with maintenance difficulties, it is possible to minimize the need for maintenance with the right plant selection and design. Avoiding invasive species; choosing native plant species and natural plant design helps reduce maintenance. In addition, the plants in the vertical garden are often damaged because they are grown in small pots and need frequent maintenance. Additionally, In the vertical gardens, sustainability will be provided by using plant species suitable for the local region. Native plants adapt more easily to the climate and conditions of the environment and will have a long life span (Green Business Certification Inc, 2014).

In order to contribute to biological diversity, the number of plant species used in vertical gardens should be increased. Plant diversity will also affect the ecosystem, flora and fauna as well (Başkan, 2019). Since the growing medium (soil or water) in the vertical garden is limited, the plant root cannot seek water and fertilizers and has to take them from outside. The amount of water and fertilizer kept in the soil is insufficient due to the small amount of soil in the pots. In vertical gardens, the area where the plant roots are kept should be as large as possible in order to minimize the maintenance need due to the use of fertilizer and water and the root-bound problem.

Plants can absorb large amounts of sunlight and provide insulation. Green walls have low temperature and high humidity, resulting in creating a microclimate and reducing the heat island effect (Chew & Conejos, 2016). Not only they affect indoor and outdoor air quality by supplying oxygen and removing toxic gases, plants also reduce the electronic haze in the air and also increase the humidity of the air and lower the temperature as a result of the leaves sweating (Llewellyn, 2011; Saki, 2020; Kalay, 2019; Hazel, 2012).

Its suggested that in roadside vertical gardens the landscape design should be plain and simple so that drivers do not lose concentration. For example, one or two dominant plant species should be used. The size and shape of the plants should not interfere with driver's view of the road and obstruct sunlight (Roads and Maritime Services, 2018).

Benefiting from the public participatory approach in projects design is one of the criteria for evaluating the performance of the urban management system. The fact that city residents have a role in vertical gardens design makes the design more appreciated by the users and makes the project reliable (Plummer & Taylor, 2004; Kimova, 2010).

By using BIM programs, in design process it is possible to prepare the maintenance plan of the vertical garden more realistically and quickly (Briscoe, 2020).

Naturally designed vertical gardens require less maintenance and are more sustainable than vertical gardens designed with artificial and sharp lines. A survey results proved that vertical gardens with well-kept, attractive and natural design features are aesthetically preferred in vertical gardens (Başkan, 2019).

Table 2: Plant species and design factors affecting the sustainability of the vertical garden.

NO	**2: Plant Species and Design**	**Points**
1	Low maintenance need (Green Business Certification Inc, 2014)	Required
2	Native plant species (Başkan,2019)	0-3
3	Sufficient plant diversity (Başkan,2019)	0-3
4	Sufficient pot size	0-3
5	Reduce urban heat island effect (Chew & Conejos, 2016)	0-3
6	Improve air quality (Llewellyn, 2011; Saki, 2020; Kalay, 2019; Helzel, 2012)	0-3
7	Follow roadside landscape guidelines (Roads and Maritime Services ,2018)	Required
8	Public participatory approach in design (Plummer & Taylor, 2004; Kimova, 2010)	0-3
9	BIM programs in design (Briscoe, 2020)	0-3
10	Natural plant design (Başkan, 2019)	0-3

3.3 Water and Fertilizer Usage

The quality and quantity of water and fertilizer used in the vertical gardens affect their sustainability. Depending on plant selection, some vertical gardens require a water tank, while it is possible to use less water in others (Luskin center, 2018). In landscape irrigation, it is possible to protect water resources and minimize energy use by reducing the utilized drinking water, natural surface water and groundwater withdrawals. However, if edible plants are grown in the vertical garden, the irrigation water should not harm human health. For instance, when it rains, the water needs of the plants can be naturally met. In addition, it can be used later by keeping rain water (Green Business Certification Inc, 2014). By using a soil moisture meter automatic drip irrigation can be stopped and delayed according to the situation (Maldonado et al., 2019) and by this mean they will assist natural hydrologic cycle and reduce urban runoff and flooding risk (Lau & Mah, 2018; Kew et al., 2014; Loh, 2008). Also, depending on the design, some vertical gardens can be used for rainwater treatment and gray water reuse (Masi et al., 2016)

Excessive use of inorganic fertilizers, especially in edible plants, cause health and environmental issues. Meanwhile, raw materials used in inorganic fertilizers are costly and generally need to be imported to the in developing countries. Analysis should be done to determine the amount of fertilizer in the soil and should not be used more than necessary (Yılmaz, 2019).

Table 3: Water and fertilizer usage factors affecting the sustainability of the vertical garden.

NO	3: Water and Fertilizer Usage	Points
1	Right amount of water (Luskin center,2018; Green Business Certification Inc, 2014)	Required
2	Use of rainwater (Green Business Certification Inc, 2014; Maldonado et al., 2019)	0-3
3	Rainwater management (Kew et al., 2014; Lau ve Mah, 2018; Loh, 2008)	0-3
4	Gray water treatment (Masi et al., 2016)	0-3
5	Right amount of fertilizing (Yılmaz, 2019)	Required

3.4 Implementation System and Process

Implementation of portable or easy to reinstall vertical gardens can reduce the amount of construction waste that has become a serious environmental problem in many large cities and is a significant step

towards sustainability. Also using light construction materials and avoiding from complex and heavy supporting structures is another aspect which can help in reaching sustainability (Begum et al., 2006).

Considering the nearby buildings and entire neighborhood, abandoned vertical gardens potentially can lead to vandalism. This negatively affects the surrounding buildings and spreads the unwanted consequences caused by vandalism. In addition, the wrong design, application and maintenance of green walls which are used on the building facades cause problems such as dampness and overload and adversely affect the surrounding buildings (Luskin Center, 2018).

Also particularly during the construction process of vertical gardens minimizing the carbon emissions, plastic and other construction wastes along with protection of water and soil especially in large scale implementations significantly will assist sustainability (Green Business Certification Inc, 2014; Hussin et al., 2013).

Table 4: Implementation system and process factors affecting the sustainability of the vertical garden.

NO	4: Implementation System and Process	Points
1	Portable and reinstall able structure (Begum et al.,2006)	0-3
2	Light structure (Begum et al.,2006)	0-3
3	Conserve surrounding structures (Luskin Center,2018)	Required
4	Protect environment during construction (Green Business Certification Inc, 2014; Hussin et al.,2013)	Required

3.5 Applied Technologies and Energy Efficiency

Experiments have indicated that vertical gardens applied to the building facades can cause a thermal insulation and provide energy efficiency up to 58.9% (Mazzali et al., 2013; Coma et al., 2017). In order to have a healthy and simultaneously energy efficient vertical gardens, humidity, water and air temperature, light, pH and water level can be measured by means of sensors. It is possible to control these factors remotely with the designed applications. The use of these technologies improves plant health and energy efficiency, quality and quantity of the products and helps to reach more efficient gardens. Using up-to-date technologies can create an opportunity for the growth of the agricultural

market in vertical gardens. It also saves money and time (Palermo & Turco, 2020; Lau, 2018; Maldonado et al., 2019).

Using renewable energies like solar and wind for providing the electrical energy required for irrigation, lighting and automatic sensors use will make vertical garden systems more sustainable. Therefore, as a result of the project area analysis, determining the most suitable renewable energy resource is the first step in this regard (Green Business Certification Inc, 2014). In indoor vertical gardens, artificial light rays can affect the plant differently according to their wavelengths. While, some wavelengths lead to more crops and flowers, some can be ignored by the plant. Since wavelengths can be adjusted in LED lights, they easily provide the desired light for the plant. Thus, depending on the purpose of vertical gardening and the growth stage of the plants, an appropriate light wave can be emitted and unnecessary light and energy will not be wasted. This situation accelerates the achievement of the desired results while saving energy and money (Çakır, 2019).

Vertical gardens with Hydroponic, Aquaponic, Aeroponic and Biofiltration techniques have their own irrigation systems, while vertical gardens with soil are irrigated differently. Rainwater is sufficient for some vertical soil gardens due to their design and the meteorological characteristics of their location. However, in vertical gardens located in other open or closed areas, automatic low pressure drip irrigation systems are generally used (Develi Uyar, 2018). In this system, it is aimed to give a small amount of water to the plant at frequent intervals (Qasim, 2019; Aksu, 2019).

Table 5: Applied technologies and energy efficiency factors affecting the sustainability of the vertical garden.

NO	5: Applied Technologies and Energy Efficiency	Points
1	Increasing energy efficiency by being on a building facade (Mazzali et al., 2013; Coma et al., 2017)	0-3
2	Used technologies (Palermo, 2020; Lau, 2018; Maldonado et al., 2019)	0-3
3	Using renewable energies (Green Business Certification Inc, 2014)	0-3
4	Artificial lights used to grow indoor plants (Çakır, 2019)	0-3
5	Right irrigation system (Qasim, 2019; Develi Uyar, 2018; Aksu, 2019)	0-3

3.6 Material Selection

The use of materials that are not convenient to the environment in some of the vertical gardens applied today is seen as a move against the main purpose of vertical gardens and negatively affects the sustainability of the vertical garden. When plastic wastes are released into the environment, they will remain for years and will cause pollution (Öç, 2013; Günaydın, 2019; Örnek, 2011).

Recycling can be a potential solution, however requires lots of cost, energy and professionalism. As a result, plastic consumption should be minimized in all of the stages of vertical garden applications. In case use of plastic materials will be inevitable due to the project's needs, it should be preferred to use pre-recycled materials which will be recycle able again in the future. If the materials used in vertical garden construction are domestically produced, it will help the structure to be more sustainable. The selection of local materials has a positive effect on the economy, as well as supporting local producers (Öç, 2013).

Table 6: Material selection factors affecting the sustainability of the vertical garden.

NO	6: Material Selection	Points
1	Using materials that have the least impact on the environment (Öç, 2013; Günaydın, 2019; Örnek, 2011)	0-3
2	Using recyclable materials (Öç, 2013; Günaydın, 2019)	0-3
3	Using recycled materials (Öç, 2013; Günaydın, 2019)	0-3
4	Using domestic materials (Öç, 2013)	0-3

3.7 User's Utility

Trainings on plants, agriculture and sustainability can be organized for children and adults in vertical gardens in school yards, playgrounds and parks. In this way, users can follow the features and processes of vertical gardens by trying them closely on-site and have a positive approach to the project. Furthermore, vertical gardens have a noticeable role in urban agriculture. According to the researches and practices carried out in the last 20 years, urban agriculture while reducing the effects of global warming, also increases the quality of life in cities and assists sustainable infrastructure (Skar, 2019).

Vertical garden applications also help local economy growth by providing employment opportunities during construction and purchasing local materials and services. It supports the local economy if the materials used in the practice are domestic goods and if workers are recruited among local and particularly low-income population of the city. In addition, the recruitment of trained people helps to spread vocational and technical education (Green Business Certification Inc, 2014).

One of the other effects and benefits of some architectural structures on the daily life of city users is that they make it easier to find their way. Navigating means finding an individual's destination without delay and stress. A vertical garden with this feature is important both for the users and for the brand identity of the surrounding area (Sönmez, 2015).

Table 7: User's utility factors affecting the sustainability of the vertical garden.

NO	7: User's Utility	Points
1	Providing training and encouragement (Green Business Certification Inc, 2014)	0-3
2	Use for urban agriculture (Skar, 2019)	0-3
3	Supporting the local economy (Green Business Certification Inc, 2014)	0-3
4	Making it easier to find direction (Sönmez, 2015)	0-3

3.8 maintenance

The maintenance phase of the vertical garden is one of the most important issues affecting its sustainability. The unexpectedly high maintenance costs of some vertical gardens explain why they're actually unsustainable. Very high maintenance costs are due to the constant change of plants, large amounts of irrigation and fertilizing, and high energy use (Başkan, 2019). Additionally, vertical gardens near busy traffic roads need more maintenance due to air and noise pollution (Ndiokwere, 1984; Khalid and others, 2018; Elkoca, 2003; Nuhoğlu, 1993). To meet the maintenance needs of vertical gardens, many employees use large vehicles and cranes for long hours. In vertical gardens on the roadside, this situation negatively affects the traffic and sometimes causes accidents. Also, pots of vertical gardens on the roadside may fall on vehicles and cause accidents. On the other hand, quiet and dark places where there are no visitors are prone to the vandalism behavior. The implemented vertical gardens in such places will require further maintenance (Tarakcı, 2003; Olgun, 2013).

Finally, a maintenance plan is necessary for briefly explaining the strategies of the project and the tasks that must be done continuously for ensuring sustainability of vertical gardens in the long term basis. The maintenance plan should be prepared in cooperation with designers and maintenance personnel, on a short and long term basis (Green Business Certification Inc, 2014).

Table 8: Maintenance factors affecting the sustainability of the vertical garden.

NO	8: Maintenance	Points
1	Low maintenance frequency and cost (Başkan, 2019)	Required
2	Not blocking the traffic during the maintenance period (Ndiokwere, 1984; Khalid et al., 2018; Elkoca, 2003; Nuhoğlu, 1993)	Required
3	Lack of potential for vandalism (Tarakcı, 2003) (Olgun, 2013)	Required
4	Maintenance plan (Green Business Certification Inc, 2014)	0-3

4.Conclusion:

In this century, that resource management issue become more important than ever and the self-sustaining systems are a necessity not an optional approach. In this context for self-sustaining vertical gardens, several aspects need to be considered in their design, implementation, and utilization of these green systems as mentioned in this study. Also, it is tried to assign fair and general scores to each criterion to provide a guideline for evaluating the sustainability of any vertical garden to improving their positive outcomes and reducing unwanted and undesired ones. The presented guideline is beneficial for designers, contractors, researchers, and companies active in this area and will help them to evaluate the vertical gardens from early design to post-construction. This research will enable to improve the understanding of resource management parameters which lead vertical gardens, green roofs and facades to leverage the quality in every phase.

5.Recourses:

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