Advantage of vertical farming over horizontal farming in achieving sustainable city, Baghdad city-commercial street case study

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Abstract. The research deals with the concept of vertical Farming as one of the modern concepts that emerged with the sustainable cities trends, because of limited green areas, increasing population and the lack of necessary ingredients for horizontal urban agriculture (water-energy-land), and the use of land for more profitable purposes such as commercial, residential or administrative use. Thus, the research problem emerged for the cognitive need to explore the importance and advantage of vertical Farming over horizontal Farming and the possibilities of achieving sustainable cities. The hypothesis of the research states that vertical Farming in its various forms is an essential part of sustainable city components for its social, economic advantages in general and environmental advantages in particular. Therefore, the research aims to define the possibilities of vertical Farming as an essential component of the urban context, in addition to achieving sustainable cities, and the results of their application by default to achieve environmental sustainability at the urban level in the city of Baghdad within a commercial street.

1. Introduction

The Specialized Studies of urban agriculture refers to that agriculture has been linked to the rural environment away from the cities, although it is the basic of civilizations establishment and the emergence of major cities. Solomon emphasizes that food and civilization are the key elements of the human experience [1]. While (Eric) points out that there is an intellectual difference in the way of dealing with agriculture in previous eras from the Current eras, in the Current eras agriculture has been separated from the urban environment due to the combination of three major forces (modern era - industrial revolution - urban development and expansion). This has led to the gradual decay of agriculture and its harmonious relationship with the urban environment, thus forming many obstacles to urban agriculture, including (the problem of high land prices and weak green infrastructure in the city [2], pollution of the urban environment [3], food shortages and high prices, and losing recreation and relaxation places [4]). Thus Cities have become a centre of sophisticated and attractive industries for rural people [5] [6]. This has led urban planners and designers to recognize the importance of urban agriculture and integrate it into the urban context as an important urban component which is compatible with global trends towards sustainability [7], but the traditional agriculture integrating with existing urban systems and the process of development policies do not suit to the nature of the practices of traditional agriculture and requirements. From here the need arises to a new model for agriculture which is the (Vertical Farming).

2. Vertical farming
Horizontal agriculture on the surface of the land is the traditional form of agriculture throughout history, but with the expansion of urban population density and increased demand for land in the cities for more profitable uses, and the lack of resources that are compatible with the nature and requirements of traditional farming practices [8]. For that, The needed for alternative model of agriculture has been emerged, which is the horizontal agriculture on the roofs of the buildings (is the new model that helped to create green areas within cities to take advantage of those abandoned and inactive areas on the one hand and the lack of sufficient areas for agriculture on the ground on the other) (figure 1) [9]. However, this model of agriculture has many drawbacks and it can be summarized as follows in Table 1:

Table 1. shows the disadvantages of horizontal agriculture (researcher)

| Sequence | The side | Disadvantages |
|----------|----------|---------------|
| 1        | Environmental | 1. Horizontal agriculture on the roofs of the buildings works to purify and reduce the temperature of air that is near to the vegetation (air above the building) only. Without air in the general environment of the street, that contains a lot of pollutants and harmful gases [20].  
2. Horizontal agriculture on the roofs of the buildings does not contribute to the sound insulation, which is resulting from the practices of daily life within the city, especially the noise of vehicles [21].  
3. Traditional horizontal agriculture relies on solar energy as well as the energy from other artificial sources to operate tillage, irrigation, harvesting and other requirements for food production [22].  
4. The rate of evaporation of horizontal agriculture (green ceilings) is very low, as its impact on the local climate is lower (determined by the nearby air layer only) [23].  
5. Traditional horizontal agriculture does not see as an “environmentally friendly” activity due to harmful emissions from production and transportation. Agricultural crops require the use of large quantities of chemical pesticides and have a longer production rate [24]. |
| 2        | Social | 1. Horizontal agriculture is performed on the roofs of buildings, which makes it outside the viewing angle (not within the field of view and sight) ) [25] |
| 3        | Economic | 1. Horizontal agriculture on the roofs of the buildings is exposed to the direct sunlight all the day times, especially in hot dry conditions such as the climate of Iraq, which makes it vulnerable to damage, where this roof cover loses its value in a short period of time and the process of watering and maintaining difficult as well as the problems that occur Planting takes place in special containers [26] [27].  
2. Horizontal agriculture requires a large area of food production, for example, horizontal agriculture requires an area of not less than 72 m horizontally to produce 150 kg of vegetables per month with constant monitoring and care [28].  
3. Traditional horizontal agriculture uses approximately 300-400 liter of water to produce 1 kg of vegetables [29].  
4. Traditional horizontal agriculture consumes large quantities of raw materials such as seeds, soil, water and food [30].  
5. Traditional horizontal agriculture does not provide support the local economy and therefore the high costs it requires in addition to losses |
resulting from transport, storage and waste of energy [31].

Therefore, the need for another model of urban agriculture was represented by vertical farming (a model of agriculture that is carried out in vertical and different forms inside or outside the buildings and at different levels within the multi-story building (figure 2) [11]. The vertical farming model is one of the forms of sustainable agriculture that has the potential to be an alternative model to traditional horizontal agriculture and as a source of food supply within cities as well as the preservation of the urban environment [12]. And to be a way to take advantage of the abandoned spaces and not escape them, as this space can be abandoned warehouse space or shipping containers, or buildings dedicated entirely to vertical agriculture (in various forms inside or outside) [13]. Vertical Farming is defined as (technology that is based on planting vertically in modern and innovative ways in different types (such as hydroponics, Aeroponics and Aquaponics), combining the architecture, technology and farms in high-rise buildings indicating the extent of the city's connection to the natural environment) [14] [15]. Thus, vertical farming provided many advantages that made it a possible model and alternative to the traditional agriculture model can be summarized as follows in Table 2:

Table 2. shows the advantages of vertical farming (researcher)

| Sequence | The side | Disadvantages |
|----------|----------|---------------|
| 1        | Environmental | 1. Vertical farming on the walls of the buildings works to purify and reduce the temperature of air near the vegetation cover, and the temperature of the wall surface, and mitigate the climate of the alleys and streets of the city by reducing the infrared emissions in a way that improves the urban environment in cities [20].
2. Vertical farming on the walls of the buildings contributes to the sound insulation, which is resulting from the practices of daily life within the city, especially the noise of vehicles [21].
3. Vertical farming relies on synthetic energy, consuming about 60 watts of energy per day to recycle ponds in addition to relying less on solar energy for food production [22].
4. Vertical farming (especially green walls) has a higher evaporation rate, where its impact on the local climate is greater (wider urban street climate) [23].
5. Vertical farming seen as an environmentally friendly activity Production and transport operations do not produce any harmful emissions. Agricultural crops do not require the use of chemical pesticides and have a shorter production rate [24]. |
| 2        | Social    | 1. Vertical farming is carried out on the walls of internal or external buildings, which makes it fall within the scope of the angle of view and not affected by the height of the building and thus contribute to the addition of aesthetic factor on the urban context [25]. |
| 3        | Economic  | 1. Vertical farming on the walls of the buildings is exposed to direct and indirect sunlight during its daily course of movement, so that it is less susceptible to damage and more durable [27] [26].
2. Vertical farming requires less space for food production, it uses only 6 m vertically to produce 150 kg of vegetables per month, which is 10 times higher than conventional horizontal agriculture [28].
3. Vertical agriculture uses 12 liters of water to produce 1 kg of vegetables, so vertical agriculture can contribute to the problem of water shortage [29].
4. Vertical farming consumes 75% less raw materials than traditional |
agriculture, where nutrients were introduced into the water without wastage from runoff [30].

5. Vertical farming provides support to the local economy by reducing the overall costs of agricultural activity by about 60% compared to traditional horizontal agriculture. Moreover, vertical farming provide a driving force in the development of innovative agricultural technologies [31].

3. The history of vertical farming
Although the concept of vertical Farming began to emerge in recent times, it is not a new innovation, but its roots extend across civilizations in previous times, the hanging gardens are in the civilization of Mesopotamia 2600 years ago, one of the first vertical farm models in the world [16] [10]. Moreover, we find the origins of vertical agriculture in the Egyptian civilization in 641 e specifically in the palaces of Fustat decorated with vertical gardens [17]. The cities of both the Greek and Roman empires 2000 years ago were also characterized by vertical agriculture as ornamental elements [18]. In 1909, Life Magazine referred to the concept of vertical farms as the high-rise building in which food is grown for human consumption [19], Gilbert Ellis Bailey referred to the term vertical farming in 1915 in his book Vertical Farming, which is how plants grow vertically at a deeper level than the surface of the earth using explosive technology [20]. Professor Stanley Hart White also referred to the concept of vertical agriculture in 1938 through his invention, which combines the architectural structure and vegetation of the new art of green architecture at the time [21]. Patrick Blanc also referred to the important role of vertical green spaces in the cities in his book (Vertical Garden: From Nature to the City), stressing the importance and necessity of "returning nature to cities" [22]. The architect (Ken Yeang) stressed the importance of vertical farming in his designs that he applied in the first multi-use skyscraper includes vertical farming [19]. Dickson Despommier developed the idea of vertical farms in 1999, and pointed out its importance in being a sustainable choice for its ability to provide solutions to urban problems resulting from traditional farming methods. So he described the vertical farming system (-It is an integrated system has the potential to produce large quantities of agricultural crops within a small area) [23].
4. Forms of vertical urban farms

Vertical farming takes different forms that can be classified into several types:

4.1. Buildings devoted entirely to vertical farming (Despommier skyscrapers)

It is a multi-story building, each floor includes several layers stacked on top of each other specially designed for the production of large quantities of plant crops and fish, and equipped with special systems and components ranging from crop cultivation to harvest and according to advanced techniques that simulate the natural environment of plants. The idea of this breed of agriculture to offer a new practical approach to prevent further encroachment on the landscape in the urban context (figure 3) [23].

![Figure 3](image)

**Figure 3.** Proposal to design a farm entirely dedicated to vertical agriculture incorporating all the advanced technologies in Australia by ODESIGN [23].

4.2. Vertical farming within the mixed-use building

In this type of vertical farms, agriculture is integrated with existing residential, administrative or commercial uses, and the building becomes multi-use, thus achieving this integration productive urban units. Where studies have shown that the process of integrating vertical farming activities with other uses and using the percentage of total land area (20:5:50). Using 50% of the total area of the building for residential units, 5% for commercial units, and 20% for agricultural units ensures high economic efficiency and provides a healthy, comprehensive and sustainable lifestyle (figure 4) [24].
4.3. Vertical farming within shipping containers
Growing crops in shipping containers is one of the most promising and recently proposed high-potential methods, as it provides a flexible and scalable means of producing food throughout the year in a variety of climates and shipping containers are characterized by mobility, regularity, simplicity, productivity and efficiency and be on two types mobile (Grow trainer), and fixed (Arctic growing system) (figure 5) [25]

4.4. Vertical green wall
Green Wall refers to all systems that can be applied in greening a vertical wall such as solid and glass exterior walls, interior walls and dividing walls, which are used as decorative elements for decoration and the shading and packaging of buildings [50]. As well as elements contributing to the promotion of the urban environment through biodiversity, air purification, reduce temperatures and reduce the impact of urban heat islands and thus achieve the sustainability of the building, vertical green walls are classified into several categories (such as vertical green facades, living walls) (figure 6) [51] [52].
5. The role of vertical agriculture in the production of sustainable cities

A sustainable city is defined as (a city where a better quality of life is achieved along with policies that effectively reduce the demand for resources (energy, water, etc.), resulting in a self-sufficient system [26]. The idea of a sustainable city has emerged as a political initiative in response to the deterioration in the urban environment since the twentieth century. Thus, vertical farming plays an important and effective role in achieving the sustainability of urban areas through the possibilities provided at the environmental, social and economic level. The importance that the agricultural system can be part of In the recent decades, it has become clear that the way we deal with agriculture poses a threat to our health and the health of our ecosystem. On the other hand, climate change forces us to rethink in the way of integrated agriculture in the urban fabric and as a means to achieve sustainable cities [27]. This requires the adoption of policies, which is based on legislation by the public sector, responsible bodies, governments and municipalities, and others, which encourage citizens to carry out these events and through awareness and educational initiatives undertaken by non-governmental bodies in the private sectors that disseminate knowledge about the importance of integrating vertical farming practices in existing buildings (Such as green balconies, internal and external green walls, etc.) including [28] [29]:

- Encouraging urban planners to incorporate vertical farming activities into urban land use.
- Review the actual regulations for urban assessment and incorporate vertical farming practices into zoning plans where agriculture is permitted.
- Encourage multiple-use and community participation in the management of green areas in the city with the rest of the uses.

Which will lead to:
- Develop the local economic level of the city, especially if the vertical farming projects are based on profitable commercial and social plans
- Equality in the distribution of land uses to satisfy all the requirements of the urban population (commercial, residential, economic and psychological).
- Easy access to food production centers.
- Encourage civic and community participation.
- A cultural vision of the city.

The process of integrating vertical farming into the urban environment takes place at two levels:
- A single building level (whether the building is occupied by residential, administrative or commercial functions, abandoned building, or a new building entirely dedicated to vertical farming) [24].
- Urban and planning levels (doubling and repeating the spread of vertical farming on the wider urban level, such as at the level of a locality or a commercial street, etc.) [30].

This will lead to many advantages (environmental, social and economic) as shows in Table 3:
Table 3. Advantages of Integrating Vertical farming in Urban Environment [25] [20]

| Advantages | The advantages |
|------------|----------------|
| 1. Environmental advantages | • Improve the urban climate and reduce the phenomenon of urban heat islands  
• Protecting agricultural crops from weather disasters and climate change  
• Water purification and sustainability  
• Conservation of natural resources  
• Reduce fossil fuel consumption  
• Improving the degree of thermal insulation of the building  
• Optimization of air quality  
• Sound and noise insulation  
• Creating an enabling environment for biodiversity |
| 2. Social advantages | • Achieve mental and spiritual health  
• Provide employment opportunities  
• Provide opportunities for education  
• Health insurance  
• Secure aesthetic aspects |
| 3. Economic advantages | • Increase food production  
• Secure organic and healthy crops  
• Energy saving |

Through these advantages resulting from the potential of vertical farming, sustainable cities are realized in their different names, as shown in (figure 7):

Figure 7. The role of vertical farming in achieving sustainable cities (researcher) based
6. The efficiency of vertical farming in achieving environmental sustainability at the urban level in Baghdad city

Baghdad is one of the overcrowded cities with hot and dry climates, and with high levels of (UHI) that are affected by direct solar radiation, increasing levels of urbanization-population and building densities are expected to increase air temperature (Ta) inside the cities higher levels than the surrounding rural areas. This leads to thermal discomfort for urban occupants, thus Vertical farming is one of an important strategies adopted to mitigate the phenomenon of (UHI) and through the environmental advantages resulting from it, have an active role in improving the climate of the Local environment. The research applied by default vertical farming on a pattern of commercial streets in the city of Baghdad, specifically AL-Karrada Street inside (the fact that this street is witnessing a high turnout of the population throughout the day and with varying densities and features many attractive activities for the goers). its characterized by medium-rise buildings on both sides of the street at a height of 15 m and width of 15 m. using the three-dimensional program (Envi-met v.4.4.3) to analyze and evaluate the parameters studied in the urban environment (urban environmental simulation) were studied: ambient air temperature (Ta), average radiation temperature (Tmrt) and relative humidity (RH) and find out how far Saw vertical farming on the thermal comfort of the external environment of the region and its impact on the attendees of this street (figure 8).

Figure 8. shows the location of the street and the data entered on the two cases (the actual situation and the default) /Researcher
Table 4. Details of initialization input parameters for the simulations in ENVI-met

| Data Type   | Parameter                                                                 | Value                          |
|-------------|---------------------------------------------------------------------------|--------------------------------|
| General     | Data of start the simulation                                              | 15 July 2015                   |
|             | Simulation starting time                                                  | 7:00 A.M.                      |
|             | Simulation duration                                                       | 20 hours                       |
| Initial data| Wind Speed in 10 m ab. Ground [m/s] wind direction (0:N..90:E..180:S..270:W..) | 2.00                           |
|             | Roughness Length z0 at Reference Point [m]                                | 0.1                            |
|             | Specific Humidity in 2500 [g water/kg air] factor of Shortwave adjustment (0.5 to 1.5) | 7.0 0.9                        |
|             | Initial Temperature Atmosphere[K]                                         | 315.250                       |
| Soil data   | Initial temperature /RH Upper Layer (0-20 cm)                             | 310.0 K/ 10%                   |
|             | Initial temperature /RH Middle Layer (20-50 cm)                           | 300.0 K/50%                   |
|             | Initial temperature /RH Deep Layer (below 50 cm)                          | 293.0 K/60%                   |
| Building Material properties | Albedo (%)                   | Wall: 0.3 | Roof: 0.3                   |
|             | Thermal conductivity (W/m.K)                                              | 1.3                            | 1.9                            |
| Surface Material | Albedo (%)                  | Asphalt Street: 0.2           |
|             |                                                                           | Concrete pavement gray: 0.5   |
| LBC TYPES   | LBC For T, q and TKE (1:open, 2: forced, 3:cyclic)                        | 2                              |
| Façade Greening | LAI                         | 1.50                           |
|             | LAD                         | 1.00                           |
|             | Albedo of substrate          | 0.02                           |
|             | Air Gap between Substrate and Wall | 1.00                  |
|             | Albedo of plant              | 0.20000                       |
|             | Transmittance               | 0.30000                       |

In this study, each case was modelled with a domain dimension of 60 x 60 x 30 and a resolution of 2m x 2m x 2m, making a total model area of 120m x 120m x 60m. Two different scenarios are created such as AN, BG. The first letter represents area pattern while the second letter represents the selected scenario such as no green (N), green (G). as shows in Table 5:

Table 5. case study scenarios

| Scenarios | Model                                                      |
|-----------|------------------------------------------------------------|
| AN        | No Façade Green plants (scenario without vertical greening) |
| BG        | With Façade Green plants (scenario with vertical greening) |

7. Results and discussions

7.1. Air Temperature (Ta)
In the first scenario (AN), which simulates the commercial street without vertical greening (Karrada Street inside Baghdad), the maximum temperature rise was found (46.34 °C) at 3 PM, and the maximum temperature drop was (34.00 °C) at 6 AM. In the second scenario (BG) which simulates the reality of the commercial street with the virtual vertical greening of the two main street facades,
the maximum temperature was found (45.03°C) at 2 PM, and the maximum temperature drop was (33.40°C) at 6 AM. As show in (figure 9 and 10).

Thus, we conclude the effectiveness of the green vertical cover in reducing the air temperature of the outer space according to the ratio (length/width) and the area of the street where the green vertical cover spread, and through vertical planting, the external air temperature was reduced by one degree Celsius during daylight hours. Overnight per day (the difference in the average air temperature between the scenario (AN) and (BG) was (1.4 - 1 ° C), and the external air temperature could drop even more if vertical farming was over larger areas spreading.

7.2. Mean Radiant Temperature (Tmrt)
In the first scenario (AN) which simulates the commercial street without vertical greening found that the maximum rise in the value of (Tmrt) was (82.04°C ) at 3 PM, and the maximum drop in the value of (Tmrt) was (28.92°C) at 5 AM, In the second scenario (BG) which simulates the commercial street with default vertical greening of the two main street facades, the maximum rise in the value of (Tmrt) was found (79.51°C)  at 2 PM , and the maximum drop in the value of (Tmrt) was found (28.06°C) at 5 AM . as show in (Figure 11 and 12).

Thus, we can conclude the effectiveness of the green vertical cover in reducing the average radiation temperature in the outer space by two degrees Celsius during the day and night hours per day according to the ratio (length / width) and the area of the street where the green vertical cover spread (difference in rate (Tmrt) Between the scenarios (AN) and (BG) was (2.53 ° C), And it is possible that
the average radiation temperature would decrease at a greater rate if vertical farming was spreading over a larger area.

7.3. Relative Humidity (RH)
In the first scenario (AN) which simulates the commercial street without vertical greening found that the maximum rise in the value of (RH) was (24.20%) at 6 AM, and the maximum drop in the value of (RH) was (10.15%) at 1 PM. In the second scenario (BG) which simulates the commercial street with default vertical greening of the two main street facades, the maximum rise in (RH) value was found (25.25%) at 6 AM, and the maximum drop in (RH) value was (11.49%) at 1 PM, as shown in (figure 13 and 14).

![Figure 13](image1.png)  
**Figure 13.** Measure the value (RH) in the scenario (AN).

![Figure 14](image2.png)  
**Figure 14.** Measuring the value of (RH) in the scenario (BG).

Thus, we conclude that with the vertical greening of the two main facades of the commercial street, the value of (RH) in the outer spaces increases by (1° C) according to the ratio (length / width) and the area of the street where the green vertical cover spread so (the difference in the rate (RH) between the scenario (AN) and (BG) was 1° C). The value of (RH) could increase even more if vertical farming spread over a larger area. On the other hand, higher wind speeds helped to achieve better thermal comfort values in the outer spaces, and fit the standards of thermal comfort in the Warm dry environments.

8. Conclusions
- Traditional horizontal agriculture is the basis for the establishment of the first civilizations, but it has been gradually separated from the cities due to the combination of three main forces (modern era - industrial revolution - urban development and expansion), which led to the need to search for alternative urban agricultural solutions.
- Vertical farming is a form of sustainable agriculture that has the potential to be the alternative to traditional agriculture and it is defined as the effectiveness that combines the architecture, technology and agriculture in high rise buildings, indicating the extent of the interconnectedness of city life with the natural environment.
- The concept of vertical farming is not a new concept, but has a history rooted across civilizations in previous eras and has been used for multiple purposes aesthetic and productive, including diverse varieties, every attempt to vertical greening (using available and sophisticated techniques), whether an internal or external environments fall under Vertical farming.
- Vertical farming is a proactive approach that has a preference over horizontal agriculture, which seeks to achieve sustainability in the cities through the advantages that are available in the driving pillars of each city (environmental, social and economic) and different levels vary depending on the level of use of agriculture, whether at the level of the building or urban level. The construction of vertical farm requires relatively small areas compared with traditional farming, and through a multi-
story building, we will be able to increase the proportion of Green Area, thus doubling production. Vertical farming thus addresses the problem of land shortage.

- Vertical farming greatly affects the urban landscape of the city, where it adds a factor of beauty and well-being and connects the inhabitants with nature, encourages walking and convergence throughout the city and supports the biodiversity in the urban environment, which helps to produce a (livable city), (Walkable city).

- Vertical farming works on plant production under controlled climatic conditions away from external climatic conditions.

- Vertical farming (green walls) form contributes well to improving and purifying the climate and reducing urban heat islands by lowering the average temperature (Tmrt) and air temperature (Ta) during day and night hours and thus reduce the thermal loads on the building and obtain thermal comfort recommends research and provide vertical green spaces on areas larger than the walls of buildings in the urban environment.

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