A Comparative Analysis of Vertical Agriculture Systems in Residential Apartments

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***Abstract*— Vertical farming, an agriculture method allows crops to be grown in an indoor setting with variable stacking systems, controlled temperate, LED lighting and irrigated through hydroponics, aeroponics or aquaponics. This paper reviews existing methods and techniques used for this growing field and its relevance to sustainable urban systems. This paper discusses the need for incorporating urban agriculture in cities, which are majorly importing food. The emerging need arises from the need to address issues such as food waste, food miles, food security and growing population. A review of types of structures suitable for vertical farming and a comparison of various farming technologies is done to evaluate the future urban requirements. The study takes into consideration both micro and macro scale of a city; how vertical farming can operate as a self-sustaining mechanism of buildings and how it can be replicated at community scale. The paper emphasizes on maximum utilization of the spatial context of apartments.**

Keywords—Vertical Agriculture, Spatial Context, Self-Sustaining, IoT, Urban Farming, Smart Systems, Food Waste, ICT.

I. INTRODUCTION

Urban Agriculture is expected to be a vital component of sustainable urban development worldwide with expected population expanding to nine billion by 2050 [1]. Half of the world's population lives in cities most of which are being built on farmland thus reducing the world's food production capacity. Dubai is primarily an urban development comprising of 127,621 buildings versus 6,460 rural buildings and can be rightly classified as a counterpart of the 'age of the city' [2]. Typically, Urban Agriculture incorporates farming and agriculture practices inside or in nearby regions of the city. This not just reduces the carbon footprint of growing and importing produce from distant lands but also allows for better use of existing urban resources such as compost. Incorporation of urban agriculture has been historically found and continued in Florence, which is surrounded, by orange and olive groves and wheat fields. Recently there is growing concern for incorporating urban agriculture by politicians, landscape architects and urban planners [1].

II. RESEARCH SIGNIFICANCE

A. Reduction in Food Waste

According to the UAE Food Bank the cost of discarding food in Dubai amounts to AED 282 annually [3]. In Dubai the food and beverage import in 2017 was of worth AED 48,159 which means that the majority of food consumed in UAE is imported from various regions of the world such as United States, Saudi Arabia, Free Zones, Oman, Germany, France, Neatherlands, India, Pakistan, United Kingdom, Turkey, Thailand, China, Brazil, Australia, Indonesia, Japan, Jordan, Canada, Sweden, Greece, Chile, Sri Lanka, Morocco, Cyprus and many more [4].

B. Adaptive Utilization of Built Context

The agriculture footprint required to feed the residents of Dubai would require conversion of huge tracts of desert land into greenhouses with specialized labor and conditioned environment. Hence the desert context of Dubai with its air rights and rapid urban growth renders more preferable location for establishing vertical urban agriculture. Apartment buildings of Dubai estimate to 432,023 most of which provide the possibility of adaptive reuse of balcony spaces for urban agriculture [2]. The coexistence of apartment residents along with agricultural production will reduce labor costs of growing food otherwise in green houses. The whole system can be designed with subsidized rates and circulation of food within communities along with minimum wastage.

C. Revenue Generation

Recently innovations to make best practical use of existing resources in Dubai are the advent of vertical farms. These include commercial ventures of buildings fully comprising of vertical farms and airlines aiming to cater for their passengers and staff through plants grown in a large-scale vertical agriculture building [5-6]. Vertical agriculture as a technology for commercial and standalone types is upcoming but considering the urban footprint of the residential sector there is prime space in the form of balconies and rooftops along with available human resource in the form of residents to uptake the issue of sustainable food production on a larger scale. For all these a strong flow for consumption, circulation and storage of agricultural produce is necessary.

The vertical farming market is expected to reach $9.9 billion by 2025 in which the increased use of Internet of things (IoT) sensors for producing crops is under research [7]. Fig 1 shows a high potential for vertical farming in the market with respect to structure, lighting, hydroponic components, climate control and growing mechanisms. The recent Internet and communication technologies (ICT) can be useful in vertical farming scenario to collect the information from various places so that food is not wasted.

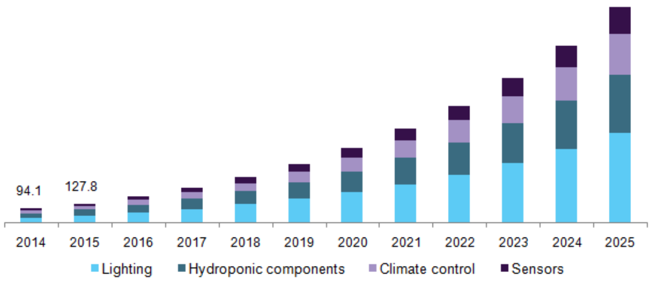

Fig 1. Canada Vertical Farming Market, 2014-2025 (USD million) [4].

III. Technologies in Vertical Farming

The intent of vertical farming is to provide maximum production with minimal environmental impacts while minimizing the use of land. Vertical farming is an upcoming area of study and further advancements and practical applications are being developed. Primarily in this field three types of technologies in vertical farming.

A. *Hydroponics*

The most widely used vertical farming system is Hydroponics in which mineral and nutrient solutions in water are used to grow plants. This method does not use soil or gravel as an inert medium. The plant roots are submerged in the nutrient solution, which can be monitored and circulated with the help of smart systems and devices.

The typical issues associated with soil based agriculture included labor intensive tasks such as weeding, tiling, dirt removal, nitrogen wastes and use of pesticides [8].

B. *Aeroponics*

The technology of Aeroponics was developed by The National Aeronautical and Space Administration (NASA) which was interested in finding efficient ways of growing plants in space. This indoor technique is a step forward from Hydroponics since it allows rapid growth of plants with no soil in an air/ mist environment. This process does not require trays to hold water and uses required 90% lesser water than an efficient hydroponic system [9]. This reduces the limitations of the type of space plants can be grown in; it can range from even a basement to a warehouse [8]. Plants produced by this method take up more vitamins and minerals and could possibly be more nutritious [9].

C. *Aquaponics*

This is a 'bio-system' which combines water and fish in the same ecosystem. Waste from the fish tank is used to fertigate the hydroponic production beds. The fish growing in the indoor ponds produce nutrient –rich waste, which acts as a feed source for the plants in the vertical farm. The hydroponic plant beds in return purify and filter the wastewater and return it to the fishponds thus acting as 'bio filters' [8]. Since Aquaponics is still at the experimental stage it is not use for large-scale commercial scale yet [9].

IV. Types of Structure Suitable for Vertical Farming

The development of vertical farms goes hand in hand with urban development. While innovative proposals for sustainable production mechanisms and structures evolve, existing urban context needs to be taken into consideration for practical application of this technology to existing urban areas. Some of the types of structures, which can serve this purpose, are:

A. *Adaptive Reuse of buildings*

Historical and vacant buildings in developing or shrinking cities can be sustainably used for vertical farming. Since there are multiple types of technologies it can be adapted for existing built context until newer structures are designed to accommodate vertical farming on a larger context. This however will require rigorous amount of studies to conclude the impact on the urban fabric. An example of adaptive reuse of buildings is 'The Plant' in Chicago, which was an old-pork packaging plant. Similarly parking structures can be used in a similar way [9].

B. *Modular Units; Shipping Containers*

Another preferred type is shipping containers which can easily be relocated with respect to the density of an urban area. These forty-foot shipping containers are fully equipped with LED lights, vertically stacked shelves and drip irrigation systems. Digitally monitored growth management systems aid in production with minimal manual input. Examples of such vertical farms include Freight Farms, Crop Box and Growtainers [9].

C. *Rooftops and balconies*

Rooftops and balconies can also be used for simplified or complex versions of vertical farming. An example of this is in the form of stacked containers made of fabricated steel structure. The planar surface of rooftops and balconies can be used in the same way. This method can produce kale, collard, greens, carrots, radishes, peppers, beans, cherry tomatoes and various herbs. Brooklyn Grange and Gotham Greens in New York are two such examples, which provide organic produce to nearby areas [8].

D. *Innovative Structures*

A number of innovative buildings designed specifically for housing vertical agriculture such as Sky Green and Crop Box are producing tropical vegetables at a mass scale. Similar to Dubai Singapore imports majority of its food with only 250 acres of land used for traditional farming. Sky Greens a commercial venture, which consists of tall A-frame systems, based on hydroponics is able to produce a wide variety of tropical vegetables such as Chinese cabbage, Lettuce, Xiao Bai Cai, Bayam, Kang Kong, Cai Xin,
and Spinach [8]. Crop Box a turn key USA bas ed venture uses containers as a built form for vertical agriculture. The capacity of one container is equivalent of growing one acre of crops. The system can be monitored through smart systems indicating lighting, nutrients, air temperature and water flow [10]. Visionary proposals such as Plantagon and La Tour Vivanete propose built structures within the urban fabric, which maximize the utilization of renewable energy and sustainable sources for production of crops [11].

V. Comparative Analysis of Farming Structural Systems Used in Vetrical Farming

Following farming structural systems is used in vertical farming: Sky Greens, Crop Box, Plantagon, La Tour Vivanete, and Gotham Greens. Various farming structures,

TABLE 1 COMPARISON OF VARIOUS FARMING STRUCTURAL SYSTEM USED IN VERTICAL FARMING

Farming Structural Systems	Advantages	Disadvantages
Sky Greens	• Produces 5 to 10 times greater per unit area than traditional farming. Space saving structural system. Large-scale production for country importing most of its food. • Environmentally friendly, low energy usage by A-Go-Gro system, low water usage, sustainable waste water management, and green technologies used. • Soil based hydroponic media allows better taste of vegetables, consistent and reliable harvest. Modular A-frame rotary system is easy to install, adjust and harvest.	• For commercial scale production only. • Building functionality is limited to vertical agriculture only.
Crop Box	• Movable structure, allows adaptive reuse of containers, can be stacked to reduce urban footprint. • Less footprint space required. • 90% less water used than greenhouse cultivation, 80% less fertilizer than conventional cultivation. • Automated record keeping.	• For commercial scale production only. • Building functionality is limited to vertical agriculture only.
Plantagon	• Proposed highly automated sphere-shaped building comprising of centrally located helix shaped structure. • Provision of integrating in existing or future office, hotel and retail space. • System allows exchange of carbon dioxide from people and oxygen from plants to people.	• Utilization of surplus food is not addressed. Food Waste issue is persisting. • Automated integration for crop production, harvesting, potential consumption and waste is not included.
La Tour Vivanete	• Proposed mix use building, residents can be employed for agriculture growth within the building; system allows exchange of carbon dioxide from people and oxygen from plants to people. • Employs energy from renewable sources such as rainwater from roof, wind energy and solar energy.	• This model doesn’t work for existing buildings. • There is no system to utilize the food among the residents in real time.
Gotham Greens	• Produces more food than traditional farming. • Advanced information and communication technology are used to control the heating cooling, irrigation and plant nutrition. • Reduces energy uses by green technology. • Socio economic benefits of community engagement, local generation of food economy, improved nutritional value of food.	• Inconvenient for the residents of the residential apartments in terms of accessibility.

which are being used on commercial scale and recent proposals for mix use types, are compared in Table 1.

The primary drawback of the farming structures which are compared in Table 1 is that these farming structures are not focused on utilization of existing structures which formulate the maximum built area of a city such as Dubai.

Secondly the integration of vertical agriculture in residential areas with regards to agriculture and food waste issues is not taken into consideration. If crops grown and cooked food is utilized to a maximum extent within each residential building the carbon footprint in transporting food waste and recycling it can be reduced. As many farming structures have been used till now in vertical farming as shown in Table 1 but still food wastes and crops grown are not utilized fully in any model. Here ICT can play a vital role through automated system which can be useful for the residents to share their information publicly.

VI. VERTICAL FARMING AS AN 'URBAN SYSTEM' ON MICRO & MACRO SCALE IN DUBAI

On a micro scale the adaptive reuse of apartment buildings by using balconies can create a self-sustaining system of food production and circulation within the building. Automated systems and advanced communication technologies can play a vital role towards this by providing user friendly software's which provide real time data. The recent internet and communication technologies (ICT) can be useful in vertical farming scenario to collect the information from various places so that food is not wasted and consumed amongst apartments on a need base.

On a macro scale the intervention of vertical farming technologies and systems requires in depth analysis of existing and future urban development. Urban footprint, economical forecast, demographics, growth patterns, employment rates, geographical conditions, carbon footprint, land use and many other pertinent factors have to be considered. Fig 2. shows a diagrammatic study of such an application in Dubai.

The existing location of most industrial units is in the outskirts of the city hence the adaptive re-use of these will mostly be limited to the outskirts of the city. An exception to this can be older structures within the Dubai. Near the waterfront areas of Dubai are pockets of vacant land or closed community developments, mostly from Al Barsha area onwards. These can be used for modular units of vertical farming which can be relocated once the construction for community development starts.

Fig 2. Study of potential Vertical Farming Systems with respect to location and urban development in Dubai [13-15].

Balconies are the prime built element, which can allow development of vertical farming on a macro scale in Dubai. This can be implemented throughout the residential and mix use areas in Dubai. Innovative structures require a permanent urban footprint and unless they are a part of the urban development guidelines, which would require them to be built at allotted distances, the location of these in the current context remains limited to new urban development towards the south.

CONCLUSION

In this manuscript, the existing technologies of vertical farming and resource requirements have been discussed. In this paper the various vertical farming methods have been compared and it is found that the available farming methods are not much useful for existing structures of Dubai. In this paper a new model has been proposed which can be useful for existing built context as well as for the new structures. The issue of food waste has not been addressed with respect to food miles in existing vertical farming methods. The proposed smart system can be useful to save food in apartments.

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