Building Integrated Vegetation Systems and their Sustainability Aspects; A Literature Review

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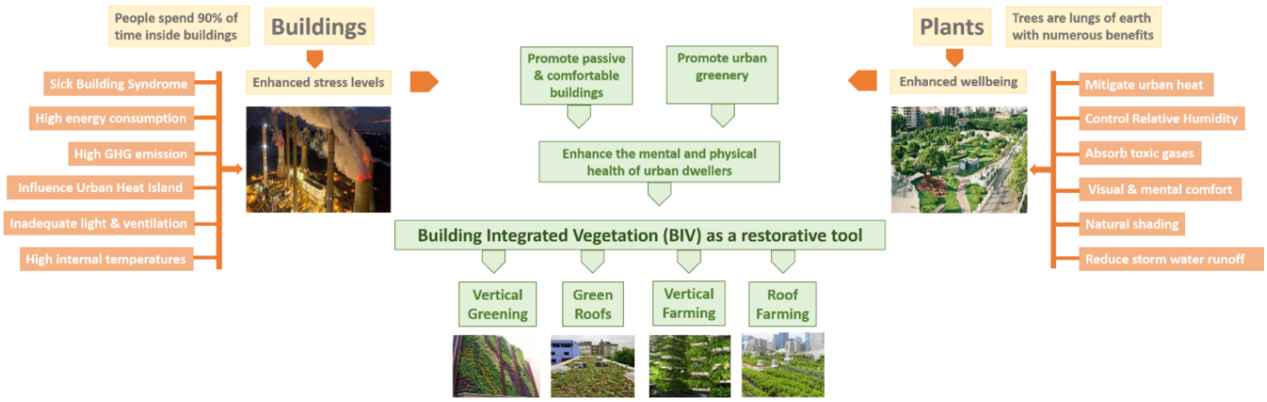
Graphical Abstract



Abstract:

There is a growing need of sustainable building development all over the world. It aims to decrease the adverse effects to the environment due to urbanization and escalating population growth. Since the building construction is considered as one of the main concerns, the priority was given to mitigate the negative impact to the environment. Therefore, incorporating sustainable elements and techniques to the buildings to regain the land loss due to construction activities in cities is currently practicing. Adding various vegetation types through different approaches, to obtain the expected results of better living condition around the building is called as building integrated vegetation systems (BIV). Vertical gardening systems, vertical farms, constructed green roofs and roof farms can be stated as main categories of BIV systems. However, there is a paucity of published critical reviews on such systems and therefore, this study is an attempt to review the overall sustainability aspects of BIV systems including environmental sustainability, economic sustainability and social sustainability. This study consists with a critical review of 114 research publications from relevant journals and online scientific databases. Finally, the identified sustainability aspects of each BIV systems were analyzed to select the best option in terms of greening a building which can be recommended for the implementations in future. Mainly, the importance of moving towards the sustainable solution which meets the food needs through BIV is finally discussed. Finally, it can be concluded that by incorporating green architecture with smart agriculture, we can expect green, healthy and productive cities which fulfill the main requirements of sustainable cities. Though there are many challenges to overcome, maintaining good management practices will give better output. Out of the 114 literature selected for this study, only 8 research papers were discussed about the drawbacks and the limitations of the BIV systems which is still having paucity of information.

Keywords: *Building Integrated Vegetation systems, Economic Sustainability, Environmental Sustainability, Social Sustainability*

1. Introduction

It is evident that many countries in the world has experienced dramatic land use change characterized by rapid industrialization and urbanization over past few decades (Li et al, 2020). Both human activities and climate change resulted in the changes of the vegetation cover in rural and urban greening. The environmental impacts associated in urban areas are significant during past few decades due to limited area availability and high population growth (Ekren, 2017; Rupasinghe & Halwatura, 2020). It is evident that, by 2030 the countries in tropical regions are expected to have more urban areas than rural areas (Rahnama, 2020. The environmental issues associated with urbanization can be identified as; urban heat island effect (UHI), water pollution, air pollution, soil pollution, light pollution, noise pollution, floods, soil erosion etc (Firman, 2009; Rupasinghe & Halwatura, 2020; Zaid et al., 2018). When the urban areas experience higher temperatures compared with their surrounding rural regions, the situation is known as UHI effects (Qiu et al, 2020).

Not only the temperature rises in urban areas outside the buildings, the indoor air conditions also given high priority since the people spent approximately 90% of their life time in indoors. Today, even breathing air in our surrounding has become a threat. Research's conducted by other countries revealed that the symptoms are so much less in the people who spent long time in outsides (Sarkosh et al, 2020). Other than that, people who spent more time in Air-Conditioned rooms and vehicles, have high risk. Such buildings having poor indoor air quality is called as "Sick" buildings. It is evident in several literature sources that, higher prevalence of symptoms among persons working in certain "sick buildings" than among workers in other buildings (Sarkosh et al, 2020; Wang et al, 2022). A general feeling of tiredness is often the most prevalent symptom of Sick Building Syndrome (SBS) and it usually starts within a few hours of coming to work, and improves within minutes of leaving the building. Further, the situation is common among professionals like, doctors, engineers, accountants, lawyers, university lecturers, state officers, bankers, software engineers, businessman, actors, actresses, singers and beauticians etc. The situations were analysed during past two, three decades and the level of pollution in Indoor Air Quality (IAQ) was found as the main reason.

Relatively low oxygen (O_2) level, high carbon dioxide (CO_2) level, high Volatile Organic Compounds (VOC) and dust particles are the reasons found for above illnesses (Wang et al, 2022).
This is due to the fact that urbanization results in a large concentration of the urban population, land use and economic activity. Such concentration results in more energy demand for residential and commercial building sectors in urban areas (Huo et al, 2020; Pomponi et al, 2020; Zhang et al, 2021). Therefore, mitigation of above-mentioned issues as much as possible is important not only for the environment, but also for the health aspects of the people live in urban areas. The construction activities coupled with the rising environmental problems become an unavoidable issue for many construction companies, government and the public. With the consideration of sustainable practices now a days the building constructions are focusing on incorporation of plants as one of the restorative tool for the issues discussed above. Since the plants are called as the lungs of the earth, it has tremendous abilities to act as one of the best architectural tool in buildings too. Their capacity of absorb CO_2 from the surrounding environment, release O_2, absorb toxic gases, temperature control, humidity control are few of them (Khan et al., 2018).
Amongst a wide range of integration of vegetation in architecture which is also known as building-integrated vegetation (BIV) system is witnessing a rapid growth in both research and market development. Therefore, integrating vegetation to a building has become very fast-growing technique. Further, the most important fact is the incorporation of above system into buildings in more sustainable way. There are various categories of BIV systems available all over the world. Vertical Gardening systems, Vertical farming, green roofs, roof farming and potted plants are few of them. When the sustainability of BIV systems is concerned, an equal importance can be given to all three aspects of sustainability. As a country which is trying to meet the sustainable development goals, it is important to know the potentials of achieving the benefits which are to be discussed under results and discussion. Among the main benefits, integration of crops as the vegetation in urban buildings is given high demand since it gives solutions for most of the current issues (Khan et al., 2018, Gomez et al, 2019; Palliwal et al, 2021, Gentry, 2019). This paper aims to fill the research gap of comparing all the sustainability aspects of main BIV systems for easy reference.

2. Materials and Methods

This study was conducted to rank the performances of different BIV Systems based on a systematic literature review answering the primary research questions of;

what is building integrated vegetation systems?

what are the sustainability aspects of BIV systems?

potential of incorporating food crops into BIV systems

The literature review consisted with peer-reviewed papers, proceedings and articles published in journals and magazines from recent years. The common scientific databases of Web of Science, Scopus, ScienceDirect, Google Scholar and Research Gate were referred to find the related publications in online platform. When searching the specific topic, the terminologies of "Building Integrated Vegetation", "Economic Sustainability", "Social Sustainability" and "Environmental Sustainability" were used in google search engine. And the publications between 2010 to 2022 were considered in reviewing process in this study. As the initial stage, all publications found were clearly examined and selected which are the most relevant papers to this study.

Systematic Framework was developed to manage the selected literature in various topics. The overall sustainability aspects of BIV systems were divided into subtopics of environmental sustainability, social sustainability, and economic sustainability with much more similarities under the common topic of Sustainable Development. Aiming to achieve a proper classification of the selected literature, a detailed data table was developed including all BIV systems studied (Mir et al, 2021; Halgamuge et al, 2021). Figure 1 shows the breakdown of the reviewed literature based on the year of publication.

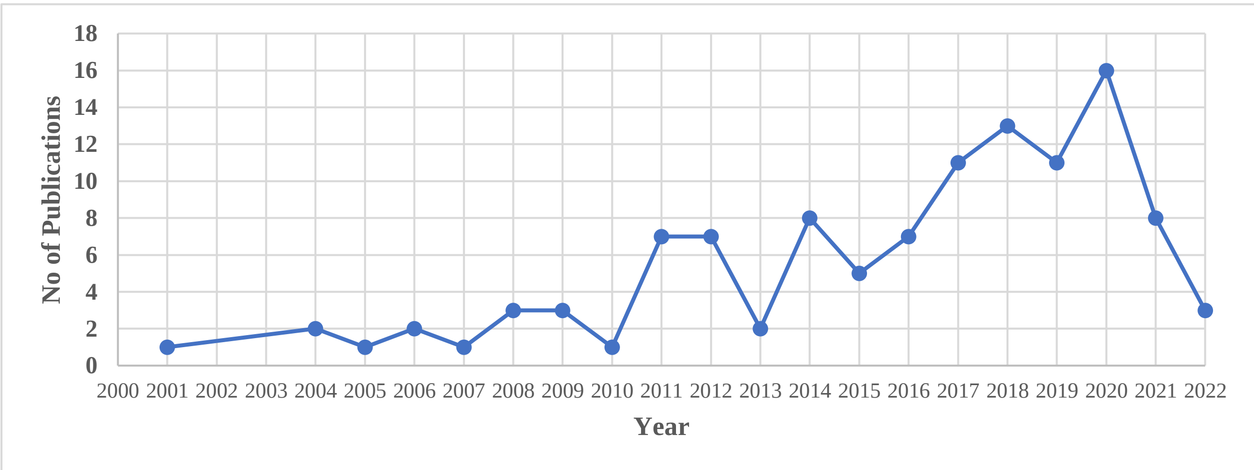


Figure 1: Distribution of articles used for this review over time

3. Results and Discussion

One or several kinds of vegetation can grow along with the buildings to fulfil various requirements. They consist with different structures and different plant types. Integrating vegetation into buildings through various systems is called as Building Integrated Vegetation (BIV) systems. BIV systems can be mainly subdivided into following categories.

i. Vertical Greenery Systems (VGS)
ii. Vertical Farms (VF)

iii. Green Roofs (GR)

iv. Roof Farms (RF)

3.1 Vertical gardening systems (VGS)

The vertical gardens are the structures supports to grow plants alone with the vertical axis from the ground to minimize impacts of rapid urbanization and provide green space alternatives to the people. There are two main categories: green facades and living walls (Figure 2). Green facades develop directly on the walls or specially designed supporting structures with climbing plants, while the roots are in the ground and the shoot system grow upwards along the building (Patel et al., 2022). When the vegetation and growing medium is established using modular panels, the system is called as a living wall (Ekren, 2017; Medl et al., 2017; Radić et al., 2019).

Figure 2: Vertical gardening systems

(Commons.wikimedia.org: Green_wall, Li Ka Shing Library, Singapore Management University-20134)

Environmental Sustainability

VGS can be set up in both indoor and outdoor and it has abundant environmental benefits. For example, vertical gardens having effective methods for improving the air quality by absorbing dust and cleaning the air by acting as natural air filters. Due to plant photosynthesis, plants consume carbon dioxide and release oxygen. Plants absorb the sun light and produce glucose and oxygen by splitting the carbon dioxide produced by living things and water. Furthermore, plants increase the oxygen level declining during the day by converting carbon dioxide gas in the atmosphere into oxygen. This makes the air clean, fresh and reduces carbon dioxide accumulation (Medl, et al., 2017; Sadeghian, 2016; Thakor et al., 2019).

VGSs can filter chemical particles in the air such as NO_2, SO_2, and CO. In addition to this gas circulation, plants absorb harmful aerosols in the air such as Volatile Organic Compounds (VOCs). The ability of the plants to remove air pollutants is called as Biofiltration and the plants do it so better and sooner (Ekren, 2017; Radić et al., 2019). These gases retained by both plants and substrate as the air is drawn through the vegetation system (Medl et al., 2017; Pandya et al., n.d.; Patel et al., 2018; Uzuhariah Abdullah et al., 2016). Another important environmental benefit of vertical greenery system is their ability to act as a natural barrier for noise control (Medl et al., 2017; Radić et al., 2019; Uzuhariah Abdullah et al., 2016). VGSs offer the best way to avoid the negative effects of noise pollution. Elements that influence noise reduction are the depth of the growing media, the materials used as structural components of the vertical garden system and the plant species used in VGS (Başdoğan & Çiğ, 2016; Ekren, 2017; Medl et al., 2017; Patel et al., 2018; Pérez et al., 2011). The cooling effect can be expected by vegetation layer or growing media. The cooling effect of VGS results from temperature reduction through evaporation from constant irrigation and transpiration from vegetation (Pan et al., 2020; Pandya et al., 2019). Further, the cooling load of the building can be reduced automatically through vegetation (Pérez et al., 2011; Radić et al., 2019; Weerasinghe, Halwatura, et al., 2020). An average increase in indoor humidity near the living wall of around 15% was observed. By taking into account the role of living walls in the humidification and the cooling of the indoor environment, they can contribute in providing comfortable conditions for the occupants, reducing the need for air-conditioning systems especially in hot and dry climates (Weerasinghe, Halwatura, et al., 2020). Urban heat island (UHI) is the maximum temperature difference between urban areas and rural areas. Applying vegetated areas in cities have crucial effects on reducing UHI , because plants absorb short wave radiation, and reduce solar re-radiation from hard surfaces (Coma et al., 2017; Ekren, 2017; Weerasinghe, Halwatura, et al., 2020). Further, the cooling effect can be obtained by direct shading to the building through the green façade or green wall (Uzuhariah Abdullah et al., 2016).

Improvement of Energy Efficiency can be obtained by simply the heat transmission into the wall and reduce the surface temperature. The vertical garden, creating an air gap between the garden and the wall, slows down the vertical movement of heat, and thus heat is captured during cold weather and isolated during hot weather (Coma et al., 2017; Ekren, 2017; Jim, 2015; Pérez et al., 2011; Weerasinghe, Halwatura, et al., 2020). Plants are natural tools for controlling microclimatic condition by their shading effects, absorption and reflection abilities (Patel et al., 2018). The water which falls to the vertical building surfaces can be captured by the plants and the growth medium of VGS VGSs by acting as a mulch and it helps to retain water to control the water runoff from building surfaces (Uzuhariah Abdullah et al., 2016). And this will lead to filter the rainwater and bring it back to the ecological cycle which is a real benefit to urban stormwater management (Ekren, 2017; Radić et al., 2019). Another main advantage is the ability of plant roots to filter the impurities in water before they enter to the natural water bodies. For example, nitrogen and phosphorus like substances are absorbed by the plant roots and use them for the plant metabolic activities, plant growth and development (Uzuhariah Abdullah et al., 2016).

Biodiversity Enrichment is the other most important aspect in vertical gardening. Implementation of vertical garden systems in urban areas create habitat for fauna and flora while increasing the green spaces in the cities (Ekren, 2017; Radić et al., 2019). Vegetations should be used to increase biodiversity and their benefits should be explored (Ekren, 2017; Manso & Castro-Gomes, 2015; Pugh et al., 2012; Singh et al., 2017). VGs create habitats for plants and animals on land that is being directly used by humans as living space. The more plant varieties are used in vertical gardens, the more biodiversity will be increased. However, it should be considered that different plant species require different habitat conditions. Therefore, plant species should be chosen carefully (Zaid et al., 2018).

Economic Sustainability

All the environmental benefits indirectly provide economic benefits from VGS systems. Protecting building infrastructure from adverse weather, protecting building envelop from external climatic stress reducing water runoff like key environmental benefits associate with monetary gain to the relevant building practicing VGS systems (Ekren, 2017; Uzuhariah Abdullah et al., 2016). Energy savings for heating and air-conditioning can be obtained since the facades contribute to the building envelope performances by creating an extra stagnant air layer which has an insulating effect and reduces the energy demand for air-conditioning (Coma et al., 2017; Jaafar et al., n.d.; Pérez et al., 2014; Rathnasiri et al., 2021; Weerasinghe, Jayasinghe, et al., 2020). Jain, (2016), stated that the energy used for cooling in a building can be reduced by 28% in warmer climates.

Increase the property value of the buildings is also another main economic benefit (Goel et al., 2022; Jaafar et al., n.d.; Jain, 2016; Uzuhariah Abdullah et al., 2016; Weerasinghe, Jayasinghe, et al., 2020). VGSs increase the value of the building they are applied on, due to their aesthetic and functional properties. Construction projects with more green spaces have more value (Ekren, 2017). Acid rain and excessive rainwater can cause deterioration of the structures of the buildings. Well-developed vertical garden systems form an effective protection against driving rain because they prevent that the rain will reach the surface of the facade. So, VGSs reduce the amount of rain which affects to the facade, and they protect structures from rainwaters' adverse effects (Ekren, 2017; Jaafar et al., n.d.; Patel et al., 2018). Further it can reduce the investments for the rainwater drainage system, if the rainwater is successfully utilized to capture by the VGSs (Radić et al., 2019).

Contribution to the acquisition of green building certification is another main advantage. Experiences of National Green Building Councils in the world reveal that the most effective way to ensure widespread using of VGS is giving green label to the buildings. This label brings some standards to the buildings and also it provides a guide to architects and engineers (Ekren, 2017; Patel et al., 2018; Radić et al., 2019). Cost reduction for the wall painting materials is also another economic benefit of the VGS (Jain, 2016; Uzuhariah Abdullah et al., 2016).

Social Sustainability

The VGSs greatly influence the social sustainability aspects. The human-plant interaction is a good move for regaining mental health (Lotfi et al., 2020; Pandya et al., 2019). It gives a therapeutic effect to the people living in the urban environment who suffers from depression and anxiety with the limited nature experiences (Medl et al., 2017; Weerasinghe et al., 2021; Weerasinghe, et al., 2020). VGS provides a therapeutic effect by inducing a psychological wellbeing through the presence of vegetation (Manso & Castro-Gomes, 2015; Radić et al., 2019). A study showed that green plants in the working places reduce absence of the employees by 5-15%, in the classrooms reduced the stress level and increased productivity of the student by 12% etc (Medl et al., 2017).

Impact of the VGs on health can be experienced by people and might be related to time spent around them. It is reported that symptoms such as headache can be eliminated through VGSs and can improve the quality of the work environment (Pandya et al., 2019). Another important factor affecting the comfort of the occupants is noise. It is known that noisy environments are stressful and annoying and prevent people from working at the full capacity. Further it is stated that, improve patient recovery rate and higher resistance to illness is also common health advantages of implementing VGSs (Manso & Castro-Gomes, 2015; Radić et al., 2019; Uzuhariah Abdullah et al., 2016). The aesthetical value can be increased with the vertical garden practices, by providing freshness and greenness to the built environment (Radić et al., 2019). Further, the deformed, aesthetically weak structure surfaces can be covered with plants and urban image can be restored (Jaafar et al., n.d.; Jain, 2016; Manso & Castro-Gomes, 2015; Medl et al., 2017; Uzuhariah Abdullah et al., 2016; Weerasinghe, et al., 2020).

Capacity of creating new job opportunities in the market when and where necessary with the popularization of this concept is another valuable social sustainability aspect identified through this literature review (Medl et al., 2017; Patel et al., 2018). Further, VGS can be used to grow some crops and can obtain a valuable output as a solution for the limited area availability in urban areas for cultivation (Singh, et al., 2017). New educational opportunity is identified if the school curriculum allows students to experience the VGS in schools and to learn how the VGS is integrated within a classroom learning environment (Radić et al., 2019; Weerasinghe, et al., 2020). Meanwhile, the VGSs can act as a space separator, visual barrier or as a partition material to provide privacy (Lotfi et al., 2020).

3.2 Vertical Farms (VF)

VF is considered as practicing crop cultivation in urban high-rise structures which use the common urban agriculture methods such as hydroponics and aeroponics to produce more yields faster (Despommier, 2011b). Though it is commonly referred as large-scale operation, the home-based farming systems are now demanding. When the valuable food crops are introduced as the plants in Vertical Gardening, the benefits are tremendous and they are referred to as VFs. It can lead to provide space for crop growth and allow year-round crop production (Despommier, 2011b; Nwosisi et al., 2017; X. P. Song et al., 2018). All the environmental, social and economic benefits discussed under VGS are common to the vertical farming since it is one of the extended versions of the existing VGSs. Therefore, only the new sustainability aspects which are unique to the VF are highlight here (Figure 3).

Figure 3: Racks of vegetables in a glasshouse design with hydroponics (Source: Sky Greens 2017; Benke and Tomkins, 2017)

Environmental Sustainability

Providing more reliable food supply throughout the year is the main advantage of Vertical farming which provides a potential solution to the escalating food crisis. Due to the reduction of transport distances, a net reduction in transport-associated energy requirements for foods can be expected. Therefore, the agricultural footprint, can be greatly reduced and the VF concept can popularize among the community, regardless of location. Low energy consuming harvesting; very less amount of water than outdoor farming, safer crops without risk from human fecal contamination can be expected (Despommier, 2011b).

The controlled growing conditions in such a VF system allow a reduction of Agro-chemical usage (Nwosisi et al., 2017). Some vertical farming operations use organic farming concepts which is more environmentally friendly. And further it leads to reduce the agricultural footprint, since they have the potential to be stacked, which is so common in vertical farming (Beacham et al., 2019;

Despommier, 2011b; Nwosisi et al., 2017). Plants would be grown using technologies such as drip irrigation, aeroponics, or hydroponics and that leads to eliminate the possibility of pest and disease attacks and associate losses even without toxic pesticides (Meinen et al., 2018b). Further, vertical gardens create a different perception and open a place for different design concepts (Patel et al., 2018).

Vertical farming also cuts greenhouse-gas emissions and therefore supports adaptation and mitigation with respect to climate change (Benke & Tomkins, 2017). Shortening that distance of food purchasing will save on the use of fossil fuels, and lower the amount of greenhouse gasses in the atmosphere. Further, the transport costs related to the entire network of facilities close to the point of sale would dramatically decrease including travel times, storage and transport costs in the entire process (Beacham et al., 2019; Benke & Tomkins, 2017; Besthorn, 2013; Despommier, 2011b; Kosorić et al., 2019).

Economic sustainability

Vertical farming provides accessibility to organic food by agricultural production which is having high market demand (Nwosisi et al., 2017). Reliable harvest, low labor costs, increased growing areas, improved productivity and capacity to grow wide range of crops are highlighted as main economic benefits (Despommier, 2011b). It immediately increases the yield per acre of any crop by multiples based on the number of floors the VF has. Maximum growth rates and cost-effective operations can be obtained due to maintaining optimum nutrient and mineral quality, optimum water quality, and optimum light quantity in VFs. Further it is said that the production overheads would decrease by 30% from the VFs (Benke & Tomkins, 2017; Meinen et al., 2018a).

Efficient water usage is the next, most important factor. Sustainable water management practices are utilized with all organic wastes being composted at the farm to ensure the use of safe, high-quality fertilizers with 70% - 80% less water compared to the traditional agriculture (Al-Kodmany, 2018; Despommier, 2011b). VFs would use around 10% of the water required for traditional open field farming (Beacham et al., 2019; Benke & Tomkins, 2017). VFs inside the city limits can result in a significant reduction in food miles (Beacham et al., 2019). The post-harvest losses also minimal due to less spoilages due to less transportation distances and the crop loss due to adverse weather events is minimal. Thus, it improves the food security (Despommier, 2011b; Nwosisi et al., 2017; J. S. Song et al., 2010).

New employment and research opportunities can be expected through this new technology. VFs contribute to job creation. The VF functions at maximum efficiency: managing nurseries, transplanting seedlings into the VF, all other agronomic practices including resource management (e.g., water, nutrients, growing systems, lighting systems, automation, etc.), monitoring plant growth and development, developing pollination strategies, harvesting, distributing the harvest to the consumers or local suppliers. Other job opportunities include Information Technology personnel, human resource management, and business office personnel etc (Başdoğan & Çiğ, 2016). Wide spectrum of job descriptions describes the work force in a typical large indoor growing facility: management of the nursery; transplanting seedlings into the VF; resource procurement and management etc (Despommier, 2011).

The footprint of the vertical system is small but can produce significantly more per unit area than traditional farms. It can also be customized to suit different crop requirements and varying environments. Further the research shows that VF can provide ten times more growing areas compared to the traditional methods. Also, the cost for fertilizer and other agro chemicals also very low compared with the traditional agriculture (Basdogen and Cig, 2016).

The VF would be fully monitored, controlled, and automated for the quality output of the products (Despommier, 2011b; Touliatos et al., 2016). Increased productivity, tasty vegetables, easy to install and maintenance, better ergonomics and automation (Kosorić et al., 2019; Winkler et al., 2019). Considerable reduction of weeding, watering, fertilizing, and controlling pests and diseases (X. P. Song et al., 2018; Utami et al., 2012). Further, it has been calculated that of the total greenhouse gas (GHG) emission of food systems, production accounts for 83%, while transport only accounts for 11% (Despommier, 2011b). Global warming mitigation, because they lower the levels of CO_2 emissions and help mitigate climate change.

Social Sustainability

Interaction of the people living in the urban environment with the nature is limited and this causes depression and anxiety. Horticulture has a therapy field regulating human-plant relationship to reduce stress, fear, anger, and blood pressure and muscle tension. (Başdoğan & Çiğ, 2016; Lotfi et al., 2020; Patel et al., 2018; Raji et al., 2015). Plants create places for recreation and rest, and it is proved that contact with nature has psychological impact and increases human health and wellbeing (Patel et al., 2018). Stress reduction and lower obesity are achieved by proximity to green areas. Vertical gardens take attention like the natural environments and affect the negative thoughts like meditation (Besthorn, 2013; Lotfi et al., 2020; Raji et al., 2015).

Tropical leafy vegetables are grown in special soil-based media, which contribute to good tasting vegetables with good yields. Organic vertical gardening is sustainable and can be employed successfully in an organic management system to produce vegetables and herbs in urban communities which is again an aesthetically pleasing to all the people involved in the entire process (Al-Kodmany, 2020; Jürkenbeck et al., 2019b; Nadal et al., 2018).

An excellent way for a family to bond while growing their own food will give a positive influence on health and well-being of users (Jürkenbeck et al., 2019; Kosorić et al., 2019b; Pérez-Urrestarazu et al., 2017). Greater consumption of fresh vegetables/herbs improves the quality of nutrition. This is a source of physical activity which helps keep the elderly healthy and active. VFs reduce stress and enhance psychological well-being, increase self-satisfaction etc. VFs provide fresher vegetables than those sold at the market. Vegetables growing on VPFs can be collected when needed (Kosorić et al., 2019b; Lotfi et al., 2020; Nadal et al., 2018).

Increased social sustainability and enriched social life of users is another advantage expected (Kosorić et al., 2019b; Lotfi et al., 2020; Nadal et al., 2018; Pérez-Urrestarazu et al., 2017; Specht et al., 2019). New business and job opportunities are created in the market when the local governments and private sector started vertical garden practices for urban memory and identity in the institutional green market (Başdoğan & Çiğ, 2016; Ling et al., 2018; Nadal et al., 2018; Patel et al., 2018; Pérez-Urrestarazu et al., 2017).

Aesthetic appearance, building's property value, visual interest and marketability all will upgrade with the building integrated vegetation systems. However, having proper maintenance is essential, as a poor state will cause exactly the opposite, undesired effect (Pérez-Urrestarazu et al., 2017). Humans naturally request compound greenery in cities and urban areas and change gray and soulless surfaces to green screens Provide an added ecological and esthetic value that is highly appreciated by current clients (Despommier, 2011a; Kosorić et al., 2019; Patel et al., 2018).

It is very probable to provide educational facilities through Vertical Farming, providing information on ideas and methods of food production and use (Pérez-Urrestarazu et al., 2017). Due to the reduction of available green areas in the cities, people have to live in front of gray walls (Başdoğan & Çiğ, 2016; Despommier, 2011b; Patel et al., 2018). Vertical farming is very much important to have healthy, chemical free diet when all the agronomic practices are maintaining organically (Despommier, 2011b; Jürkenbeck et al., 2019; Ling et al., 2018a; Nadal et al., 2018; Patel et al., 2018). From a physiological perspective, vertical gardens might have an impact of reducing heart rate and stress, headache (Basdogan, 2009; Lotfi et al., 2020).

3.3 Green Roofs (GR)

The roof is a significant part of the building envelope comprising approximately 20%–30% of the total impervious area in an urban environment (Carter & Keeler, 2008). Conventional roofs exacerbate the urban environmental issues triggered by unplanned urbanization (Santamouris, 2014). However, given due consideration conventional roofs can be converted into sustainable outputs (Sailor et al., 2012). A green roof is a building roof that is entirely or partially covered with vegetation and growth medium (Yu et al., 2017) (Figure 4). They are also referred to as roof gardens or living roofs (Francis & Lorimer, 2011). GRs help to compensate for the loss of urban greenery and help to combat the negative impacts of urbanization (Vijayaraghavan, 2016; Xiao et al., 2014; Yok & Sia, 2009).

GRs provide a myriad of social, environmental and economic benefits to urban areas (State of Victoria et al., 2014; Yok & Sia, 2009). They help to improve the quality of life of urban dwellers by providing visual relief and localized cooling in dense urban centers (Carter & Keeler, 2008b; Francis & Lorimer, 2011; Yok & Sia, 2009). GRsGreen roofs help to reduce the urban heat island effects and they are a technological solution for urban storm water management (Ampim et al., 2010). Moreover, green roofs help to improve building performance and reduce building energy consumption, thus reducing its environmental impacts. Furthermore, GRs help cities reach important indicators for ecological harmony (Carter & Keeler, 2008).

Therefore, GRs make significant contributions to the environmental, ecological, social and economic realms of cities. As these tangible benefits are increasingly realized, GRs will become an integral part of the urban environment (Yok & Sia, 2009).

Figure 4: A picture of a green roof (Source architizer.com)

Environmental Sustainability

The salient features of the built environment can lead to numerous environmental impacts in cities (Lundholm, 2006). However, GRs offer an innovative means to transform the harsh and barren roofs into attractive living roofs that benefit the environment. GRs help to integrate ecosystem and biodiversity values to the urban environment. They help to re-establish the vanishing green space in the urban areas (Vijayaraghavan & Raja, 2014). GRs provide habitat for local fauna and creates an ecological environment with greater bio-diversity (Rowe & Getter, 2006). They offer a safe environment for birds, insects and other plants (Vijayaraghavan, 2016). Thus, GRs help to combat the impact of urban development on natural ecosystems.

Moreover, green roofing is a modern and highly efficient solution for urban environmental problems. Plants have a natural ability to absorb air pollutants. Therefore, the plants on a GR positively impact the ambient air quality in urban areas (Seyedabadi et al., 2021). GRs can also be used as a noise control mechanism in buildings (Rowe & Getter, 2006; Van Renterghem & Botteldooren, 2011; Yang et al., 2008). GRs act as a sound insulator for the roof system and prevent noise from road, rail and air traffic from entering the building (Van Renterghem & Botteldooren, 2011). Connelly & Hodgson, (2013) reported that vegetated roofs can reduce transmission of sound into the building by up to 10dB and 20dB in the low and mid frequency ranges, respectively. Therefore, incorporating GRs in buildings can offer numerous direct and indirect environmental benefits to metropolitan areas (Vijayaraghavan, 2016).

Economic Sustainability

Green roofs provide a variety of economic benefits to metropolitan areas. The vegetated surface of a green roof has a higher albedo than conventional roofs. Therefore, buildings equipped with GRs absorbs less heat from solar radiation (Lundholm, 2006). Furthermore, a GR acts as an insulation layer and prevents energy loss from the building as well as heat gain into the building. The shading provided by plants on the rooftop, further prevents the transmittance of heat into the building. Data obtained from Singapore have shown that GRs have the potential to reduce surface temperatures and the heat transmitted into the interior of buildings (Nyuk Hien et al., 2007). Further, Nyuk Hien et al., (2007) reported that extensive GRs in Singapore have a maximum heat reduction greater than 60%. The thermal buffer effect provided by green roofs leads to significant reductions in energy demand for cooling and heating (Perkins & Joyce, 2012a; Xiao et al., 2014). Studies conducted in Switzerland have reported that GRs yield up to 4 GW of energy savings per year (Besir & Cuce, 2018). A study conducted in Greece revealed that GRs can reduce the energy utilized for cooling up to 48%, depending on the area covered by the green roof. The same study reported that indoor temperature reductions of up to 4K is possible by using GRs (Niachou et al., 2001). Improved building energy performance and reduced energy consumption in buildings translate to economic gains (Xiao et al., 2014).

Furthermore, GRs are an impressive remedy for the UHI effect (Morau et al., 2012; Sailor et al., 2012). The natural cooling effect provided by plants, due to the evapotranspiration process, cools the ambient air and reduces the demand for air-conditioning. This, in turn, leads to significant reductions in building energy consumption and allows building owners to enjoy economic benefits (Perkins & Joyce, 2012).

GRs also provide other economic incentives such as increased life of roofs and improved building protection (Ampim et al., 2010; Rowe & Getter, 2006). GRs help to protect the roof membrane from extreme heat, wind and ultra violet radiation. Furthermore, due to the presence of vegetation and thick substrate layer, the daily expansion and contraction of the roofing membrane is prevented (Vijayaraghavan, 2016). Thus, GRs have a longer life span when compared with conventional roofs.

Moreover, as a technological tool for urban storm water management, GRs provide economic benefits to urban areas though storm water control. Grs help to reduce the speed and quantity of stormwater run-off (Speak et al., 2012) reported that intensive GRs can retain on average about 65.7% of the stormwater runoff. This reduces the pressure on a city's storm water management infrastructure thus preventing local flooding (Dunnett and Kingsbury, 2004; D.B. Rowe and Getter, 2006; Yok and Sia, 2009).

Social Sustainability

GRs provide a variety of services to the urban environment and help cities attain social sustainability. The integration of GRs to buildings in urban areas has the potential to increase the quality of the urban environment. The cooling effect provided by green roofs help to improve the urban microclimate. Implementation of GRs on a large scale can reduce the UHI effect and relieve the worsening of urban temperatures (Lin et al., 2008; Perkins & Joyce, 2012b; Seyedabadi et al., 2021; Weng & Yang, 2004; Wong & Yu, 2005). Santamouris, (2014), reported that large-scale application of green roofs can reduce ambient temperature by 0.3 to 3°C. Cooler ambient temperatures ensures that metropolitan areas are livable and comfortable for urban habitants.

Furthermore, GRs can be used to mitigate air pollution in urban areas. The ambient air in urban areas often contains elevated levels of air pollutants which are harmful to human health. Plants have the ability to clean the air through various direct and indirect processes (Rowe & Getter, 2006; Yuan et al., 2019). Moreover, GRs improve the sound insulation in buildings preventing noise from traffic and other urban activities from entering buildings. Improved urban air quality and noise control provided by GRs make urban environments are more habitable for urban dwellers (Perkins & Joyce, 2012b; Rowe & Getter, 2006).

GRs add greenery to an otherwise barren urban landscape and the presence of greenery has a major psychological impact on urban dwellers. GRs provide greater aesthetic enjoyment and supports psychological restoration (D.-K. Lee, 2014; White & Gatersleben, 2011). (K. E. Lee et al., 2015) reported that micro-breaks spent viewing a GR can help to promote greater attention control. Similar studies have also reported that viewing GRs can reduce stress and improve performance. A post occupancy evaluation conducted on rooftop gardens in hospitals revealed that the presence of GRs provide psychological benefits for patients including emotion respite (Reeve et al., 2017).

GRs provide accessible green space in dense urban environments. It helps to relieve the pressures of urban living and provides horticultural therapy (Dunnett & Kingsbury, 2004; Rowe & Getter, 2006). Furthermore, GRs enhance the visual aesthetics of cities, and raises the value of real estate (Ampim et al., 2010; Ichihara & Cohen, 2011; Manso & Castro-Gomes, 2015; Reeve et al., 2017;

Santamouris, 2014; Vijayaraghavan, 2016). Therefore, GRs help cities achieve their goals for social sustainability.

3.4 Rooftop Farming (RF)

Rooftop farming is a type of urban agriculture, in which food is grown on the tops of building roofs. There are different approaches which can be followed in terms of cultivating crops on the top of the roofs (Figure 5). As discussed in above three BIV systems, the rooftop farming also make significant contributions to the environmental, ecological, social and economic aspects of cities (Grard et al., 2018).

Environmental Sustainability

Since the urban roof farming is practicing near the city areas, it cut the transportations distances and the related carbon footprint is minimum (Benis & Ferrão, 2018). Reduction in greenhouse gas emissions, effective use of rainwater, reduction in energy consumption, and improvement of air quality are the identified environmental benefits of roof farms according to Kim et al., (2018) and Ledesma et al., (2020). With the implementation of rainwater catchment system in urban areas use them for roof farming is a good strategy to follow (Ugai, 2016).

Taking the multiple uses of waste resources such as wastewater, waste heat, and organic waste from residences and buildings are potential uses of rooftop farming (Specht et al., 2014). And one of the tremendous benefits of roof farming is reduce the heat island effect. The air quality can be improved by reducing the air pollutants by the associated the crops grown in the roof farms (Hui, 2014; Ugai, 2016)

Figure 5: Rooftop garden (newsroom.unsw.edu.au)

Economic Sustainability

Fresh Crop production throughout the year can be obtained by converting the by turning the urban roof top areas into productive spaces (Benis & Ferrão, 2018; Ledesma et al., 2020; Specht et al., 2014). More economically attractive building space usage is practiced when people incorporate related technologies like solar power into these farming systems (Benis & Ferrão, 2018; Buehler & Junge, 2016). Further, with the proper maintenance of roof farming technology, it can claim for certifications like LEED (Leadership in Energy and Environmental Design)and other related environmental certifications. The roof life can be extended by protecting the roof from ultra violet light with proper waterproofing membranes combined with green roofs (Ugai, 2016).

Social Sustainability

This roof top farming helps to encourage the social works, education and job trainings, aiming a powerful community (Benis & Ferrão, 2018; Buehler & Junge, 2016). Further, it provides learning and educational opportunities for the interested parties (Benis & Ferrão, 2018). Kim et al., (2018) stated that as per the survey conducted by them, 71.6% have indicated that they are willing to have green roofs on their own residential buildings, with 58.1% preferring roof gardens and 41.9% preferring roof farms. Reasons for selecting roof farms were highlighted as their desire to grow their own food and as an opportunity to their children to learn (Kim et al., 2018).

The negative feelings of painfulness, non-comfortability, lethargy, and frustration can be converted to pleasant, peaceful, and motivated and satisfied due to these roof farming implementations (Kim et al., 2018; Triguero-Mas et al., 2020). Food self-sufficiency can be expected (Buehler & Junge, 2016). Enhancing its social cohesion is another advantage (Thomaier et al., 2015). This review critically presents the concept of Building Integrated vegetation systems, how it is defined, what are the main categories and how it can contribute to the sustainability aspects which are discussing today. Then the different systems were compared over their environmental, economic and social sustainability aspects.

All the BIV Systems have an outstanding benefit, including environmental, economic and social perspectives. The advantages become more and more vital when the edible gardening is practicing along with existing BIV systems such as vertical farms and roof farms. Through vertical farming and roof farming, long-term economic and social impacts can be expected (Zaid et al., 2018). And become a strong proponent of climate change mitigation strategy for urban areas.

With edible gardening concept we can achieve the sustainable development goals of zero hunger, good health and wellbeing, sustainable cities and communities, life on land etc, fully or partially. There is a huge potential for growing crops along with the BIV systems. According to zaid et al, 2018, the climbing vegetables such as, *Phaseolus vulgaris* (Common Bean), *Vigna unguiculata sesquipedalis* (Long Bean), *Pisum sativum* (Pea), *Cucumis sativus* (Cucumber) and *Sechium edule* (Chayote) can be easily grown and train in the VGS (Zaid et al., 2018). Further, the fruits like Guava, Lemon, Papaya, Grapes, Green Chili, Pumpkin, Squash, Onion, Garlic, Coriander leaves, Tomato, Mushroom, Leafy vegetables also can be recommended (Chowdhury et al., 2020). A per the Buehler & Junge, (2016) leafy vegetables, tomato, herbs, pepper, eggplant, micro greens, cucumber, carrot, raddish etc, were recommended as building integrated food crops.

Table 1: Comparison of each discussed BIV systems against sustainability aspects

Criteria	Vertical Greenery Systems	Vertical Farms	Green roofs	Roof Farms
Environmental Sustainability				
Improve the air quality, absorb dust and clean the air by acting as natural air filter	√	√	√	√
Consume carbon dioxide, absorb the sun light and produce glucose and release oxygen	√	√	√	√
Filter chemical particles and aerosols in the air such as NO_2, SO_2, VOC, and CO	√	√	√	√
Act as a natural barrier for noise control	√	√	√	√
Avoid the negative effects of noise pollution	√	√	√	√
Cooling effect can be expected by vegetation layer or growing media	√	√	√	√
Increase in indoor humidity and provide comfortable conditions for the occupants	√	√	√	√
Reduce the need for air-conditioning systems	√	√	√	√
Reduce the Urban heat island (UHI) effect	√	√	√	√
Help to keep minimum building related carbon footprint	√	√	√	√
Provide direct shading to the building	√	√	√	√
Plants are natural tools for controlling microclimatic condition by their shading effects, absorption and reflection abilities	√	√	√	√
Improve the Energy Efficiency of the building	√	√	√	√
Retain water to control the water runoff from building surfaces	√	√	√	√
Filter the rainwater and bring it back to the ecological cycle which is a real benefit to urban stormwater management	√	√	√	√

Ability of plant roots to filter the impurities in water before they enter to the natural water bodies	√	√	√	√
Biodiversity Enrichment while increasing the green spaces in the cities	√	√	√	√
Provide habitat for local fauna and creates an ecological environment	√	√	√	√
Re-establish the vanishing green space in the urban areas	√	√	√	√
Provide more reliable food supply throughout the year	-	√	-	√
Potential solution to the escalating food crisis	-	√	-	√
Reduction in transport-associated energy requirements for foods can be expected	-	√	-	√
Reduce the agricultural footprint	-	√	-	√
Low energy consuming harvesting	-	√	-	√
Very less amount of water than outdoor farming	-	√		√
Taking the multiple uses of waste resources such as waste water, waste heat, organic waste from residences and buildings	√	√	√	√
Economic Sustainability				
Protect building infrastructure from adverse weather	√	√	√	√
Energy savings for heating and air-conditioning	√	√	√	√
Reduce energy used for cooling in a building	√	√	√	√
Increase the property value of the buildings	√	√	√	√
Act as an insulation layers and prevents energy loss from the building as well as heat gain into the building	√	√	√	√
Increase the aesthetic and functional value of the building	√	√	√	√
Provide effective protection against driving rain	√	√	√	√
Contribution to the acquisition of green building certification	√	√	√	√

Cost reduction for the painting materials	√	√	√	√
Provides accessibility to organic food by agricultural production	-	√	-	√
Reliable harvest, low labor costs, increased growing areas, improved productivity	-	√	-	√
Improves the food security	-	√	-	√
Sustainable water management practices	√	√	√	√
New employment and research opportunities	√	√	√	√
Fully monitored, controlled, and automated systems	√	√	√	√
Increased life of building infrastructure and improved building protection	√	√	√	√
Provide economic benefits to urban areas though storm water control	√	√	√	√
Social Sustainability				
The human-plant interaction is a good move for regaining mental health	√	√	√	√
Create places for recreation, eliminate painfulness, non-comfortability, and lethargy. And frustration can be converted to pleasant, peaceful, motivated and satisfied	√	√	√	√
Gives a therapeutic effect to the people living in the urban environment who suffers from depression and anxiety with the limited nature experiences	√	√	√	√
Provides a psychological wellbeing through the presence of vegetation	√	√	√	√
Green plants in the working places reduce absence of the employees, reduced the stress level and increased productivity	√	√	√	√
Symptoms such as headache can be eliminated improve the quality of the work environment	√	√	√	√

Provide comfort of the occupants by reducing noise	√	√	√	√
Improve patient recovery rate and higher resistance to illness	√	√	√	√
Increase the aesthetical value by providing freshness and greenness to the built environment	√	√	√	√
Can restore the deformed, aesthetically weak, corroded building surfaces, grey facades and soulless structures with plants	√	√	√	√
Capacity of creating new job opportunities in the market	√	√	√	√
Can act as a space separator, visual barrier or as a partition material to provide privacy	√	√	√	√
Edible gardening is sustainable and can be employed successfully in an organic management system to produce vegetables and herbs in urban communities which is again an aesthetically pleasing to all the people involved in the entire process	-	√	-	√
An excellent way for a family to bond while growing their own food will give a positive influence on health and well-being of users	-	√	-	√
Greater consumption of fresh vegetables/herbs improves the quality of nutrition.	-	√	-	√
Increased social sustainability and enriched social life through self-satisfaction	-	√	-	√
Educational facilities through BIV, providing information on ideas and methods of food production and use	-	√	-	√
Make urban environments are more habitable for urban dwellers	√	√	√	√

The drawbacks and the limitations of the BIV systems also needs to be discussed. The main factor to be considered is the associated installation and the maintenance costs. Keeping a BIV system requires its basic cost which have to spend at the initiations of the system and the amount which is needed to bare for the maintenance in each month is significant depending on the type of the system (Terblanche, 2019; Mahdiyar et al, 2020, Ascione et al, 2020). Type of the plant, watering system, replacements and the cleaning are few such considerations which comes as a routine.

One other concern is the lack of technical data available for the design, installation and maintenance to be used by the interested parties. If the design standards, cost calculations and return on investments (ROIs) are freely available, the construction companies can use those for their research and development. But the paucity of information is still a barrier for the future of this field. As a result, the specialized designers and constructors also a limitation (Adegun et al, 2021, Prado et al, 2021).

The situations such as pest and decease attacks, fire, breakdowns of the irrigation systems, maintenance delays are some other common natural risks associated with this. To overcome the above discussed weaknesses, the approaches like Life Cycle Assessment, Environmental Impact Assessment, and Cost Calculations can be done (Ascione et al, 2020, Mahdiyar et al, 2020, Prado et al, 2021, Senalankadhikara et al, 2022).

4. Conclusions

When the BIV systems are compared under Table 1, it shows how each system contribute to achieve the sustainability aspects. And it clearly presents how the BIV systems perform effectively when the edible plants introduced to the systems in order to obtain agricultural production. When the sustainable development goals are considered, building integrated agriculture systems can help to achieve some goals out of them. Enriching urban biodiversity, provisioning ecosystem survives, reducing food insecurity are few of them. Providing healthy food for consumption, which can be produced as an organic, and environmentally friendly way is important.

There are very limited number of people who are practicing food crop cultivation along with the buildings though they are aware of the technology. That may be due to their less motivation to adapt with new approaches, and they still hope to go with the traditional agriculture practices. If the people are well educated and aware of the tremendous benefits of urban building related agriculture a great result can be expected. As most of the practitioners are stating that they have identified a considerable different in the quality of the food. All the environmental related benefits coupled with the crop gain is really a massive achievement in urban context if people can incorporate the above potential in a better way. As per the Buehler & Junge, (2016), there are some options where the aquaponics can incorporate with crop growing which leads to maximize the harvest. Incorporating rain water harvesting, use of renewable energy, re use of waste water after simple purifications are few opportunities which can be linked in order to get the optimum advantages out of this. Further research and development are required to identify the feasibility of the suggested cop cultivation in urban setup for future improvements.

Despite the social and environmental aspects of BIV systems, the possible economic benefits by introducing edible crops is a timely concern. Even a basic knowledge on vertical farming a rooftop farming can leads to provide a solution for the food crisis. Not only that, with the proper management of urban vertical and horizontal spaces can effectively find better pathways to address the current crisis situations.

Finally, it can be concluded that by blending green architecture with smart agriculture, we can expect green, healthy and productive cities which fulfill the main requirements of sustainable cities. There are many challenges also in building integrated agriculture methods such as, monitoring and controlling of crop growing environment in an optimum level, maintaining desirable watering and nutrient supply system, proper selection of the suitable crop, pest and disease control etc. The future research opportunities are mainly based on checking the practical implementations of above discussed BIV systems to obtain the maximum advantages for the better sustainable future.

The drawbacks and the limitations of the BIV systems are listed as, installation and the maintenance costs, lack of technical data available for the design, installation and maintenance, less number of specialized designers and constructors, pest and decease attacks, breakdowns of the irrigation systems, maintenance delays etc.

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