Introduction to construction systems for integration of vegetation into built form

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ABSTRACT: Integration of biophilic elements such as Vegetation within our built environments can be a very effective means of addressing several problems of modern cities and buildings. Vegetative elements in our cities and buildings not only create a qualitatively superior micro-climate, but also have tangible benefits for occupant health and comfort. They also assist in mitigating the negative impact of the ‘concrete & glass jungles’ that we are making in our urban areas. This study looks at some typical construction systems and details that can be used in buildings to integrate vegetation (as a component of biophilic design) into the architecture of the buildings.

KEYWORDS: Architecture, biophilic design, green buildings, green roofs, green walls, urban vegetation.

I. INTRODUCTION

The aim of this study is to understand how one of its components of biophilic design, namely – ‘vegetation’ can be integrated with architectural design. There are many biophilic elements which can be incorporated in the built environment. Out of all the natural elements of biophilic design, this study focusses only on vegetation in built environment and looks at ways and means to incorporate vegetation in artificially generated human environments.

There has been a human need to be among nature throughout our evolutionary history and humanity has depended on vegetation for food, fuel and shelter. Our existence depends on being among plants. That dependence is so ingrained in our make-up that biologists now give the subconscious desire to be among vegetation, a name: ‘Biophilia.’

The 20th century was the century of urbanization. It is estimated that above half of the world population lives in urban regions, and by 2030 the urban population is expected to be twice as large as the rural population across the world. In this context we need to understand and implement ways and means to integrate greenery and vegetation into our built habitats at various scales, if we are to build liveable and healthy cities and buildings.

WHY PLANTS?: Green space, both interior and exterior are essential to architecture promoting a connection with nature. The green spaces soften the built environment creating more inviting and relaxed places while reducing the risk of sick building syndrome and aid in a person's psychological well-being. Not only can plants physically improve the environment, but they have positive psychological impacts as well. Studies performed by Roger Ulrich suggested that exposure to living plants significantly benefited overall health (1). Plants are credited with conferring many benefits to buildings and their occupants. Studies performed by NASA have found that at least one living plant per 100 square feet of floor space can help clean air in an office building. Some benefits are easy to explain in terms of the biological processes going on inside the plant, such as living plants can help combat sick building syndrome by purifying the air in indoor environments. As volatile organic substances (VOCs) are one of the causes of sick building syndrome, tropical plants are particularly good at removing these harmful VOCs from the air through natural processes like photosynthesis. By the process of photosynthesis, concentration of CO2 is reduced from surroundings and oxygen releases. Thus, it helps the occupants of buildings for fresh breathing. Trees reduce greenhouse warming by fixing carbon dioxide during photosynthesis, shades outdoor public areas for comfort and serves as a noise barrier in urban areas.

Plants can reduce air temperatures and loads on air-conditioning systems during hot summer days thus cooling a building. On the other hand, there are many benefits that scientists have found to be measurable, but for which there is no complete explanation, such as Stress reduction - studies have shown that people are less stressed when in the presence of plants. Increased productivity at work. Reduction in complaints of symptoms associated with sick building syndrome.
In short, vegetation solves most indoor and outdoor problems. Healthy air is vital for well-being in architecture which results in a healthy soul. Plants don just photo-synthesize CO2, giving out oxygen and clears air particles of unwanted chemicals. They improve air quality through re-oxygenation, humidity and temperature moderation, dust anchoring, pollution absorption and ion generation. Research conducted by Dr. Craig Knight and his colleagues at the Universities of Exeter in the UK and Groningen in the Netherlands (above figure) has examined the management of work space by comparing typical lean spaces with those enriched with - essentially ephemeral - items like indoor plants. Such enrichment resulted in increased well-being (as measured in terms of work-place comfort, identity, engagement and corporate citizenship behaviour - altruism at work) and productivity by over 15%. Furthermore, research seems to show that the improvements in comfort and well-being attributed to plants in and around buildings are far greater than any physical change they make to the environment. Even limited
In urban built form is that most adverse effects of urbanization in a sustainable manner, making cities more sustainable and healthy, and reducing pollution. The presence of green spaces can improve mental health and reduce stress levels, which can in turn lead to increased productivity and well-being of office workers. Those outcomes include psycho-physiological stress responses, task performance, emotional states, and room assessments.

In addition, some studies have investigated the effects of indoor plants on health and discomfort symptoms related to the sick building syndrome. Outside the workplace, there is evidence that exposure to plants and natural settings can improve positive mood and reduce negative mood. Findings also indicate that physiological stress is often lower after exposure to plants and nature as compared with urban settings. Furthermore, increases in well-being have been shown to coincide with less mental distress among people living in urban areas interspersed with green spaces. An obvious question is why plants and green spaces might have these beneficial psychosocial benefits. Currently, there are three classes of explanations for such findings. According to the first, plants, as living organisms, exert a beneficial influence on the climate of the working and living environment. In particular, plants are thought to be healthy because they improve air quality. In this regard, when introduced in sufficient quantity, indoor potted plants have been shown to remove most types of air-borne pollutants arising from either outdoor or indoor sources.

However, as well as objective changes in air quality, the presence of plants might also result in a perceived change in air quality. This question was also investigated by other researchers in an academic setting. They found that students who worked in an environment that had been enriched with plants reported that air quality had improved. Such data thus suggest that enriching the workplace with plants should have a positive effect on the air quality within the working environment.

The second explanation of plants’ beneficial effects centres on the evolutionary explanation that a green, planted environment reflects the natural world and thereby supports human physiology. Proponents of attention restoration theory argue that natural environments restore people’s capacity for directed attention, whereas built environments tend to deplete this capacity. The idea behind this theory is that the prolonged focus on a specific stimulus or task results in “directed attention fatigue.” Natural environments exert less demand on directed attention and encourage more effortless brain functions, thereby allowing the capacity for attention to be restored. Thus, after an interaction with natural environments, one is able to perform better on tasks that rely on directed-attention abilities. According to this view, plants in the workplace should enhance employees’ directed-attention capacity and therefore enhance their concentration and productivity levels.

Furthermore, indoor plants have been shown to remove most types of air-borne pollutants arising from either outdoor or indoor sources. This has been studied within laboratories, as well as in naturally ventilated and air-conditioned office spaces. Air pollutants, even at imperceptible levels, can cause “building-related illness” and symptoms of headache, sore eyes, nose, and throat, or nausea. Where indoor plants have been installed, staff well-being is improved with reduced sick-leave absence.

In addition, plants can refresh the air by absorbing carbon dioxide (CO₂). The importance of this is suggested by studies which show that student performance declines with increasing CO₂, as does workplace productivity. However, as well as objective changes in air quality, the presence of plants might also result in a perceived change in air quality. This question was also investigated by other researchers in an academic setting. They found that students who worked in an environment that had been enriched with plants reported that air quality had improved. Such data thus suggest that enriching the workplace with plants should have a positive effect on the air quality within the working environment. The second explanation of plants’ beneficial effects centres on the evolutionary explanation that a green, planted environment reflects the natural world and thereby supports human physiology. Proponents of attention restoration theory argue that natural environments restore people’s capacity for directed attention, whereas built environments tend to deplete this capacity. The idea behind this theory is that the prolonged focus on a specific stimulus or task results in “directed attention fatigue.” Natural environments exert less demand on directed attention and encourage more effortless brain functions, thereby allowing the capacity for attention to be restored. Thus, after an interaction with natural environments, one is able to perform better on tasks that rely on directed-attention abilities. According to this view, plants in the workplace should enhance employees’ directed-attention capacity and therefore enhance their concentration and productivity levels.

The third class of explanations moves away from physiological responses and looks more closely at the relational and managerial consequences of enrichment. The basic idea here is that enrichment of the workspace signals that attempts are being made to enhance staff well-being and “environmental comfort.” Enrichment thus communicates managerial care and attention which may in turn lead to increased attention and work engagement among employees. It also follows that if people are physically, cognitively and emotionally involved in their work there is a reduced risk of disengagement. This in turn is likely to translate into higher levels of work satisfaction, productivity and well-being. In short, enriching the environment with plants should signal managerial care and hence result in increased engagement, attention and environmental satisfaction. More broadly, this should also result in perceived improvement to psychological well-being and productivity in the workspace.

II. INCORPORATING VEGETATION IN BUILT ENVIRONMENT

Developing countries are urbanizing at a very fast pace. The proportion of younger generation in such nations at present are more in comparison to not only European or American countries but in comparison to more advanced developing countries also. People are moving towards the cities in search of jobs, better education, healthcare, etc. This migration leads to more urban sprawl, noise and air pollution and changes in weather patterns. The changes in weather patterns predicted to result from climate change, as well as potential resource shortages and economic instability. In this context, the concern behind focusing on vegetation in urban built form is that most of the cities are concentrated more into accommodating the burgeoning population which is responsible for limiting green belt expansion. Whilst many cities have historically been “green” but because of their sprawling nature, the challenge is now to maintain that same quality and character of life. The tension between development and nature conservation in cities must be resolved. The enhancement of urban green spaces is the only way, which has the potential to mitigate the adverse effects of urbanization in a sustainable manner, making cities more sustainable and healthy.
attractive and comfortable to live in. This can be achieved by working at different scales like building scale, street scale and city scale. Among these the smallest is building scale which can be initiative stage in terms of enhancing green urban spaces.

In this study, different techniques of incorporating vegetation into buildings are discussed in detail. In recent years, the incorporation of vegetation is possible in both interiors as well as exteriors. Exterior plantation can be done on roofs, sky courts and walls. While living walls, bio filters and many techniques of potted plantation can be used to grow vegetation inside. These all can make a built form and its surrounding greener.

**GREEN ROOF:** An aerial view of most urban areas shows swathes of asphalt, black tar and gravel-ballasted rooftops. These roof tops radiate a huge amount of heat in the environment. Studies shows that most traditional dark coloured roof surface absorb 70% or more the solar energy striking them, resulting in peak roof tempe rate of 65°C - 88°C. The heat absorption and monotony of these common roofs can be avoided through green roof tops. Green rooftop is an attractive way to promote environmentalism while solving the problems of conventional roofs. Green roof provides an opportunity to grow vegetation without disrupting the structure of building. In a broad sense – ‘to make neglected space of roof useful’. The term "green roof" is also referred as living roof, roof garden, eco-roof, landscaped roof and vegetated roof cover.
The term "green roof" is also referred to as living roof, roof garden, eco-roof, landscaped roof and vegetated roof cover. Green roof techniques are all about providing a surface to grow vegetation on the top of the building. This can range from lichen and moss on a roof surface to a fully landscaped space including trees and shrub. Green roofs are usually supported by a growing medium, filter sheet, drainage layer, root barrier and waterproofing membrane.

**Types of green roof:** Green roofs can be divided into two categories based on its techniques and application: built-in green roofs and modular green roofs. Further, built-in green roof technique is divided into 3 sub-categories depending on structure’s load bearing capacity, maintenance, desired plant diversity and budget: Extensive, Semi Intensive and Intensive. On the other hand, Modular techniques divide into our sub-categories depending on different types of modules used: Blanket system, Mat System, Tray System and Sack System.

**III. BUILT-IN GREEN ROOF SYSTEMS**

**Extensive green roof:** An extensive green roof system is characterized by vegetation ranging from sedums to small grasses, herbs and flowering herbaceous plants which need little maintenance and no permanent irrigation system. The growing medium depth for an extensive green roof system is typically 150 mm or less. Extensive green roof is very cost efficient compared to other types (12). In a nutshell, extensive system is shallow in soil depth and not capable of supporting larger plants but tend to be easier to maintain.

![Fig. 2.5 Types of Green Roof System](image)
**Semi-intensive green roof:** Semi-intensive green roof fall in between extensive and intensive green roof system, characterized by small herbaceous plants, ground covers, grasses and small shrubs, requiring moderate maintenance and occasional irrigation. A typical growing medium depth for a semi-intensive green roof is around 150 mm. This system is able to retain more storm water than an extensive system and supports a larger range of species of vegetation. This green roof system provides the potential of making a formal garden, but it demands higher maintenance compare to extensive system since the plants tend to need pruning, irrigation, and fertilization.

**Intensive green roof:** Intensive green roofs require the deepest soil and have the greatest impact on the structural design, but they also accommodate all types of plantings including large shrubs and trees. Intensive systems are generally used to create a big garden on the roof top. A typical growing medium depth of an intensive green roof is more than 150 mm. a significant amount of attention must be paid to the various waterproofing and root barrier details. Also, Maintenance of an intensive green roof can be quite complex.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Extensive</th>
<th>Semi-Intensive</th>
<th>Intensive</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Depth of Substrate</strong></td>
<td>150 mm or less</td>
<td>About 150 mm</td>
<td>More than 150 mm</td>
</tr>
<tr>
<td><strong>Accessibility</strong></td>
<td>Often Inaccessible</td>
<td>Partially accessible</td>
<td>Usually accessible</td>
</tr>
<tr>
<td><strong>Fully Saturated Weight</strong></td>
<td>Low (70-170 kg/m²)</td>
<td>Varies (170-290 kg/m²)</td>
<td>High (290-970 kg/m²)</td>
</tr>
<tr>
<td><strong>Plant Diversity</strong></td>
<td>Low</td>
<td>Greater than Extensive</td>
<td>Greatest</td>
</tr>
<tr>
<td><strong>Plant Communities</strong></td>
<td>Moos-Sedum-Herbs and Grasses</td>
<td>Grass- Herbs and shrubs</td>
<td>Lawn, shrubs and trees</td>
</tr>
<tr>
<td><strong>Use</strong></td>
<td>Ecological Protection layer</td>
<td>Designed green roof</td>
<td>Park like garden</td>
</tr>
<tr>
<td><strong>cost</strong></td>
<td>Low</td>
<td>Varies</td>
<td>Highest</td>
</tr>
<tr>
<td><strong>Maintenance</strong></td>
<td>Minimal</td>
<td>Varies</td>
<td>Highest</td>
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Table 2A: Comparing Extensive, Semi-Intensive and Intensive green roof techniques
Basic Structure of Built-in green roof Technique: The basic structure of a Built-in green roof technique is almost similar in all three systems (Extensive, Semi-Intensive and Intensive). A green roof requires appropriate sunlight, moisture, drainage, aeration and nutrients to the plants root systems. It is composed of a waterproof membrane, followed by a root barrier, a layer of insulation, a drainage layer, a growing medium or soil substrate and the vegetation on top. A shallow layer of gravel or pebbles are placed from 0.5 m to 1 m within the outside perimeter of the roof, providing additional drainage and access to the roof for maintenance.

MODULAR GREEN ROOF SYSTEM: Modular systems are comprised of individual pre-planted modules. The modules are capable to retain the water which makes it easier in irrigation and lighter in weight compare to Built-in systems. This system can be more expensive Due to pre-planting but once installed it takes minimal care and maintenance. In these systems, one can easily lift the whole module for the maintenance purposes and put it back without disturbing the growing medium and plants.

In this technique vegetation is grown offsite and simply placed on the existing roof to achieve complete coverage. In a modular system, drainage, soil substrate and plants are self-contained within the module with varying dimensions. When all the modules are interlocked with each other, they offer continuous roof drainage and green coverage. Modular green roof systems can be available in different depths of growing medium typically ranging from 75 mm to 300 mm. It can be applied to existing buildings and can also be changed or removed easily. Different modular green roof systems are pre cultivated blankets, vegetated mat, tray and sack systems.

Basic Structure of Modular green roof Technique: In the modular systems, the hierarchy of all the layers remains same as built-in system. The main difference in modular systems is plants, soil substrate and drainage layers are merged in the selected module.
BUILT-IT GREEN ROOF V/s MODULAR GREEN ROOF

<table>
<thead>
<tr>
<th>Built-in green roof</th>
<th>Modular green roof</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed as a series of layers and vegetation grows on it</td>
<td>Prefabricated off-site and pre-grown in nursery</td>
</tr>
<tr>
<td>Layers are not replaceable</td>
<td>Sub-divided into standard interchangeable parts</td>
</tr>
<tr>
<td>Longer installation period</td>
<td>Shorter installation period</td>
</tr>
<tr>
<td>More complex and permanent</td>
<td>Simple interface and provides portability</td>
</tr>
<tr>
<td>Needs more load baring capacity of building</td>
<td>Do not need extra load baring capacity</td>
</tr>
<tr>
<td>Maintenance is complex and costly</td>
<td>Minimal care and maintenance required</td>
</tr>
<tr>
<td>Offers more design opportunities and supports diverse plant species</td>
<td>Limited design opportunities only supports smaller plants only</td>
</tr>
<tr>
<td>Various subcontractors are needed for design and installation</td>
<td>Single contractor can handle the whole work due to less complication</td>
</tr>
</tbody>
</table>

Table 2B: Comparison between Built-in Green Roof System and Modular Green Roof System

GREEN WALL: In most of the urban areas, the major reasons behind ‘heat island effect’ are disused vertical surfaces and lack of surrounding green spaces. One of the solutions of this problem is vertical greenery which can provide cooling potential on the building surface, which is very important in hot climates. This cooling effect due to green facades has also an impact on the inner climate of the building by preventing the façade from warming up. The concept of vertical greening is not new and also recorded from the ancient times of hanging gardens of Babylonia. Today, many vertical greening systems can be used for greening the vertical surfaces which are also known as ‘vertical gardening systems’ or ‘Green wall systems’. These systems can be divided into two major categories: ‘Green Facades’ and ‘Living Walls’

Types of green Walls: Green walls system can be divided into two categories based on its techniques and application: Green Facades and Living Walls. Further, Green Facades can be divided into two sub-categories depending on maintenance, desired plant diversity and budget: Modular trellis panel System and Cable & wire-rope net system. On the other hand, Living Wall techniques can be divided into three sub-categories: Modular living walls, bio filters and Vegetated mat walls.
GREEN FACADES

Green facades are usually set outdoors, rooted in the ground or in intermediate planters or on rooftops and do not require additional irrigation system. They are a type of green wall system in which climbing plants or cascading groundcovers are supported by specially designed structures. The supporting structure can be anchored to existing walls or built as freestanding structures such as fences or columns. Self-climbing plants such as English Ivy can be used to create green walls because they can easily attach to the supporting system. The plants typically take 3 to 5 years to achieve full coverage. Modular Trellis Panel and Cable and Wire-Rope Net systems are two basic green façade systems which can be easily installed in newly built structure or existing building.

**Modular Trellis Panel System:** Modular Trellis Panel System is a rigid, light weight, three-dimensional panel made from a powder coated galvanized and welded steel wire which can support plants with grid structure. This system is designed to hold a green facade off the wall surface so that plants do not attach to the building and provides a captive growing environment for the plant with continuous supports to spread equally. The rigid panels can be stacked and joined to cover large areas and create different shapes also be used for freestanding green walls.
Cable and Wire-Rope Net System: As the name implies this system uses either cables or wire rope net. Cables can be employed on facades which are designed to support faster growing climbing plants with denser foliage. On the other hand, wire-nets can be used to support slower growing plants. These systems are more flexible, fixed at closer intervals and provide a greater degree of design applications than Modular Trellis Panel System.

LIVING WALLS: Living wall systems are composed of pre-vegetated panels or vertical modules or planted blankets that are fixed vertically to a structural wall or frame. These panels or modules can be made of plastic or polystyrene or synthetic fabric or metal which are comprised of interconnected panels that hold growing medium (soil or alternative) and built-in irrigation system. It can support a greater diversity and density of different type of plants like lush mixture of groundcovers, ferns, low shrubs, perennial flowering plants. This kind of plants are not possible in a green façade system. Due to dense plantation, living walls requires more intensive maintenance.
Modular Living Wall: A modular living wall system is emerged from the concept of modular green roof techniques. The only difference is that modules are fixed vertically. These modules are either square or rectangular panels that hold growing medium to support plant material. The composition of the growing medium can be tailored to the unique combination of plants selected according to desired design. Most of the nutrient requirements for the plants can be found in the growing media within the modules. Modular living walls need an inbuilt irrigation system which is more complex but necessary for better aesthetics. Modular systems are often pre-grown, providing an ‘instant’ green effect upon completion of the installation.
**Vegetated Mat Wall:** The vegetated mat wall is a unique form of green wall pioneered by a famous botanist Patrick Blanc. It is composed of two layers of synthetic fabric with pockets filled with the plants and growing medium. The fabric walls are supported on a frame and backed by a waterproof membrane against the building wall because of its high moisture content. Nutrients and water are distributed through an irrigation system that cycles water from the top of the system down.

![Basic structure of vegetated mat walls and different application of it](image)

Fig. 2.14 Basic structure of vegetated mat walls and different application of it
IV. BIOFILTERS

Biofilter is a relatively new and innovative technology in the world of vertical gardens. It is basically a living wall which can be integrated into a building’s infrastructure. It is designed in such a way that the indoor air flow passes through the growing medium which filters it and also provides thermal regulation. It is a hydroponic system fed by nutrient rich water which is re-circulated from a manifold located at the top of the wall and collected in a gutter at the bottom of the fabric wall system. In biofilters mostly tropical plants are used. Plant roots are sandwiched between two layers of synthetic fabric that supports microbes and a dense root mass. These root microbes remove up to 85% of the airborne volatile organic compounds (VOCs), while foliage absorbs carbon monoxide and dioxide. The plants’ natural processes produce cool fresh air that is drawn through the system by a fan and then distributed throughout the building. It can work independently and also reduce the load of building’s HVAC system.

![Biofilter Diagram](image)

Fig. 2.15 Basic structure of Biofilter and an outer view of it
V. THE WAY AHEAD

Vegetation is considered as one of the vital elements of biophilic design. This study looks at the importance and beneficial effects of vegetation and efficacious techniques to incorporate it in built form. Green spaces both interior and exterior are essential to architecture promoting a connection with nature. Integration of vast indigenous vegetation in the built environment provides a calm and restful atmosphere to enhance human behaviour and well-being. It is evident that architects and urban planners can make a bigger impact by designing vegetation incorporated built forms and urban landscapes for a healthier built environment. However, lack of knowledge, unwillingness to pay extra initial cost, maintenance and ignorance are some factors which prevent many people to step forward in this direction. There have been several innovations and new applications in developing Vegetative Systems for buildings – especially for interior spaces; like Hydroponics, etc. More and more urban people are also trying Terrace farming, which also contributes greatly to reducing the Heat Island Effect in hot climates.

Fig. 3.1 - Pasqua Urban Farm is a nine-storey office building in Tokyo that allows employees to grow and harvest their own food at work.

Fig. 3.2 - Narva has designs and sells free standing green wall systems for interior spaces.

However, in most countries, there are no specific building rules and regulations to nurture greenery in built forms. If some policy and regulatory alterations can be introduced in this context, then our cities and buildings will be much more healthier and liveable; and they will make a genuinely positive contribution for the betterment of this plant.
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