BIO-INTEGRATED ARCHITECTURAL MODULAR FAÇADE FOR URBAN BUILT ENVIRONMENT

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ABSTRACT

Like the rest of the world, tropical urban cities are undergoing tremendous population expansion. Urban heat stress is on the rise, creating the Urban Heat Island, as a result of reduced vegetation and the development of the built environment using impermeablematerials. In order to address the issue, vertical greenery systems are in demand as an adaptation to the built environment. Vertical living walls have become a popular trend globally where elongated with many benefits. However, to gain the possible benefits, comprehensive knowledge is necessary as living walls are more frequently requested by many urban residencies in Colomb, adopted as an icon for sustainability, aesthetically pleasing and visually appealing expression. Nevertheless, the emergence of novel products should be catered to the local market with less complexity addressing a low profile in cost, maintenance and durability.

The development and invention of a Bio integrated modular brick disclose an environmentally friendly living walling method which comprises a single unit where the unique design is adopted to solve the problems in the construction, installation, irrigation, drainage, water, and power supply of a vertical living wall system. A comprehensive literature review has been conducted to collectdata on mortar and brick properties, vegetation and germination, irrigation systems, and structural properties. The self-interlockingfeature of the masonry unit is designated in both the female and the male face of the unit, improving strength and balance. Also, the potting area can be utilized for soil and plants while the waterproofing layer is in between the planting area and the main structural part of the unit. Specially designed grooved have been catered for irrigation and nutrient supply pipelines with outlets. This vegetated masonry unit can be adapted to all exterior or *interior facades and for boundary walls which is low in cost, maintenanceand high in durability.*

Keywords: Bio-Integration, Modular brick, Urban Heat Island, Urban context, Vertical Living Walls

INTRODUCTION

The indirect influence of COVID-19 significant cause, economic shocks became a more important driver of food crisesin 2020. Food price surges were exacerbated by supply chain disruptions, especially in the immediate aftermath of travel restrictions, and prices remained high for a long time afterwards. Sri Lanka has a significant rural agricultural engagement whereas urban agriculture is still inemerging stages (Figure 1). The government of Sri Lanka promoted the public to engage in home gardening and has launched several programs in support. However, people living in urban areas, especially in Colombo city, are facing difficulties implementing the home garden concept due to alack of space.

The present economic crisis exacerbated by the Covid-19 pandemic which torpedoed tourism and remittances, Sri Lanka facing a shortage of foreign exchange. This situation led to an unprecedented acute economic and energy crisis,where food and energy supply have been disrupted. Due to the non-availability of fuel to generate thermal power, residential, commercial, and industries facing many difficulties due to power outbreaks. Surprisingly, space cooling accounts for more than 75% of total electricity consumption in a typical building in Sri Lanka. Residential buildings have become the most prominent energy end-use sector in an economy, absorbing 50% -70% of operational energy for internal cooling and for Heating Ventilation and Air Conditioning (HVAC) (Geekiyanage & Ramachandr, 2018). The building façade is the main component of the building envelope that separates the building interior from the outside and it has a greater potential of being the climatic filter where double skin envelop are identified as a better option to maintain comfortable indoors (Rajapaksha et al, 2015).

However, urban areas are heating more than rural contexts, where naturally available vegetated surfaces (such as grassand trees) are replaced with non-natural heat-absorbing, non-reflective, water-resistant impervious surfaces (such as concrete, and asphalt) made with anthropogenic materials which absorb high percentages of incoming solar radiation. Addressing the matter most cities adopt vegetative surfaces in terms of urban forestry such as green roofs, living walls,green facades, and green turf areas.

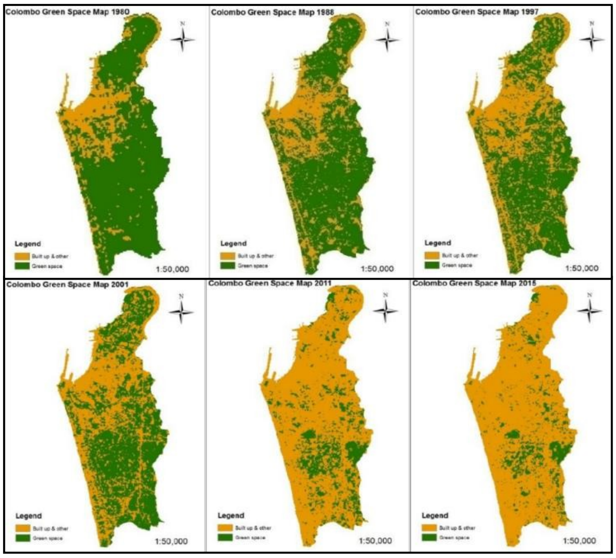

Figure 1: Colombo Green area map from 1980-2015 (Li & Pussella, 2017)

Results of the on-site investigation of the existing Vertical Greenery System revealed Living Walls to be better in thermal performance with a record of maximum temperature reduction of 10.16°C, 3.31°C, and 2.11°C in an external wall surface, internal wall surface, and internal air temperature respectively (Rupasinghe & Halwatura, 2020). Figure 2 shows the energy balance of a vegetative façade.

Furthermore, the 'Green wall' or the 'Living wall' can be an advantageous solution with substantial potential to work as an approach to the Vertical Farms solution. Vertical Farms are a new concept and philosophy for the way humanity thinks about agriculture. A goal for Vertical Farms is the eventual ability to grow to produce in city centers to avoid transportation issues and to preserve existing natural life by slowing deforestation (Villanova, et al., 2013).

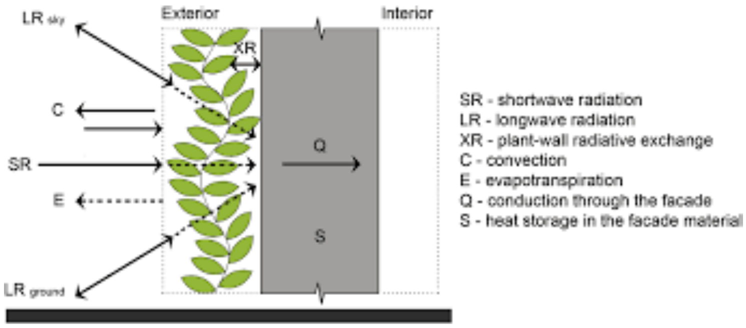

Figure 2: Thermal evaluation of a vegetative façade (Surasova, et al., 2013)

However, living walls are very expensive and cost-effective in the local market because of the structure, materials, and maintenance. Responding to the phenomenon a new bio modular brick has been developed integrating vegetationinto the façade. The brick consists of interlocking sections, plant pot area for substrate, and the plant. Along with the modular brick, the overall façade system will be developed and designed with Drainage systems, irrigation with separate sections, spate brick designs for corner bricks of the wall, and a drip tray to collect excess water. This researchstudy further intends to define an initial approximation of the energetic benefits resulting from the implementation ofa Vertical Farm Façade. Design strategies can be outlined from design and development, construction and project competition, and application of the end product.

Figure 3: Living wall system details in the Sri Lankan market and Movenpick hotel (Wall Span, 2017)

RESEARCH GAP

The use of green walls as a façade system is commonly seen in other countries. Though only a handful of buildings in Colombo are equipped with living walls, their popularity as elements promoting Green Infrastructure is increasingday by day.

It is important to assess the economic and thermal interpretation of these living wall systems in terms of installation and maintenance cost and thermal performance of the material used in the green wall structure which gives a negativeimpact on the cooling demand of the building.

Thus, it is necessary to address these factors and research one can determine the true efficiency of living walls as a climate-sensitive building element in dense urban cityscapeslike Colombo.

PROBLEM STATEMENT

During the pandemic, the country was under lockdown for months several times, over the past two years. Food supplyand transportation were on the brink. With the situation, the Government of Sri Lanka introduced a concept of 'home gardening' where people started to grow vegetables, fruits, and greens at their premises. However, people living in urban areas went through difficulties implementing the garden concept due to the lack of available space.

In the present situation, Sri Lanka is facing an economic crisis where power and food are the two major necessities that have been affected strictly. Buildings take a great amount of energy to cool the interiors, especially in the urban context. One of the major factors resulting in such conditions is the use of impervious materials in building construction which absorb more heat during the day and sag-net the hot air during the night. This paves the way forhigh electricity consumption.

ANALYSIS OF THE PROBLEM

Addressing the matter many use living walls in both local and international settings. Living walls create a specific niche in the design of urban food production systems. They provide green space for areas where land is expensive, unavailable, or unsafe for growing edible plants. Additionally, Vegetation cools buildings and the surrounding areas through the processes of shading, reducing reflected heat, and evapotranspiration. This helps in cooling the exterior façade surfaces which simultaneously moderates the energy load uses on cooling interiors.

THE RATIONALE FOR THE RESEARCH QUESTION

However, construction systems and the products of living walls in the local market are very expensive. Design andresearch efforts are needed to make vertical food production technology cost-competitive and logistically practical.

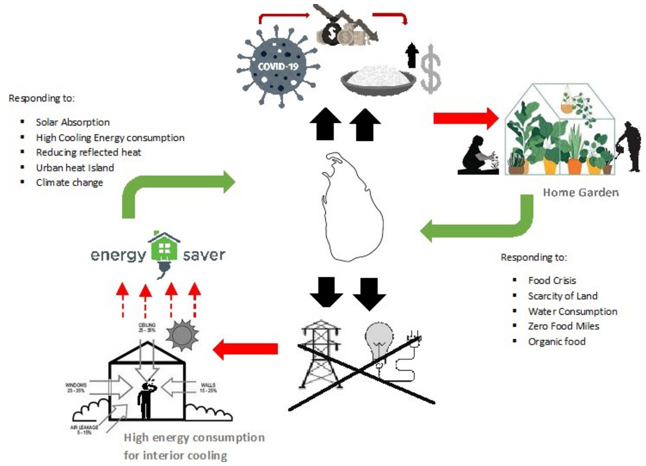

Figure 4: The aim of the study

THE OBJECTIVES OF THE STUDY

General Objective

The majority of living walls that exist today are superficial – they are structure rather than integrated within it. They are non-structural and have no real architectural purpose besides beingaesthetic. Although explorations of modular planter units exist in varying capacities with high cost and maintenance, the main objective of this research is, 'to develop a Bio integrated modular brick for urban vertical gardening in Sri Lanka'.

SPECIFIC OBJECTIVE

1. To study available vertical gardening technologies in the world.
2. To study how vertical gardening can be bio-integrated into the structural wall systems in Sri Lanka.
3. To develop a novel prototype modular brick for urban vertical gardening in Sri Lanka.

4. To check the durability and the quality standards of Bio integrated architectural modular façade.
5. To study experimentally the thermal performance of the novel Bio integrated architectural modular façade compared to existing technology.

Primarily, the study will focus on exploring a design that is both innovative in its form and function, but otherwise universally applicable beyond the context of its own creation.

RESEARCH APPROACH

Scientific Impact

From the beginning of the study to the final product sequence of developments will be carried out. Novel technologicalaspects such as vertical gardening technologies, integration, waterproofing, durability, environmental impact tests, and industrial applications will be studied and developed to bring a successful bio-integrated brick to the general market and adapt to urban building facades.

Moreover, the application of such green infrastructure provides ecosystem services such as wind and temperature moderation, mitigation of the urban heat island effect, carbon sequestration, acoustic damping, air pollution reductions, stormwater filtration, and retention of enhanced urban aesthetic and positive psychological response, increased habitat for urban pollinators and small wildlife, food production and soil protection.

Societal Impact

The adaptation of vertical gardening in urban buildings and households enhances many Socio and Cultural Services. The social awareness of the final product and poster camp aigns helps in many anthropogenic benefits such as mentalhealth, spiritual connection, artistic expression, the creation of a sense of place, recreation and well-being, regional identity, aesthetics, tourism, mobility and human health.

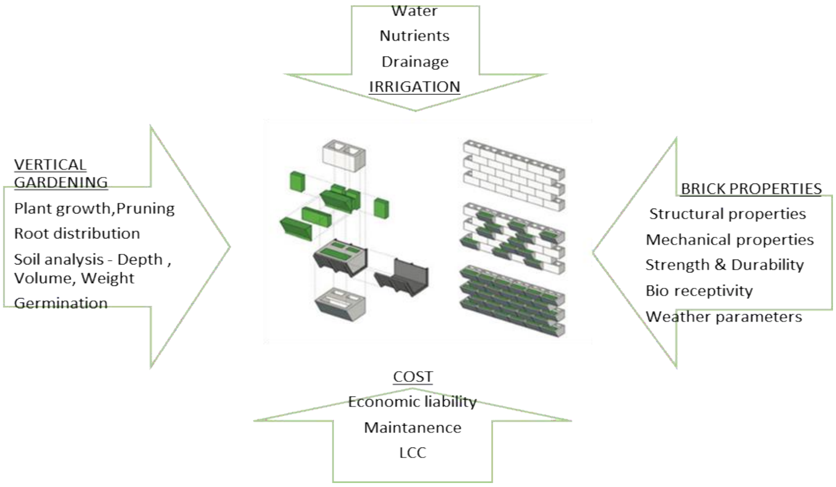

Figure 5: Expected innovative design objectives

Economic Impact

The existing local living wall products and construction systems are very high expensive. Only limited social capacityhas the ability to obtain a living wall system. However, the development of the bio modular brick addresses all the social categories while economically helping in, the proliferation of property values, reducing energy costs, expansion of food supply, and reducing the damage risk. Also, the study will be focused on local products, local tests, SL Patents, industry applications, local manufacturing and industry optimization.

A LITERATURE REVIEW

In 2021 Global Hunger Index ranked Sri Lanka as 65th out of 116 countries, with an overall 'Moderate' hunger rate. Wasting among children aged under five is among the highest in the world standing at a percentage of 15%. "Country's vulnerability to the effects of climate change means extreme weather events such as droughts, floods and landslides continue to comprise food security and nutrients" (Keck & et al, 2021).

Plantation always depends on the climate situation and temperature is the most important thing. Therefore, land surfacetemperature variation can be predicting yield and their success or failure (Department of Geography, 2016). TheHigh land surface temperature which led to the formation of the Urban heat Island phenomenon shows a great impact on urban areas than on surrounding rural areas. UHI induces through low surface albedo, building geometry and absence ofgreenery and it deteriorates the thermal comfort and well-being of city dwellers and occupants (Herath, et al., 2018).

A study conducted in Colombo and Gampaha districts study highlighted that the remarkable incident which relates to UHI is the difference in thermal properties of the surfaces where non-vegetated or built-up areas show high-temperature variations while low temperatures at vegetatedor water areas, can be [2] in the Colombo and Gampaha districts showsgrowth of mean land surface temperature ranges from 25.01°C to 27.66 °C from the year 2001 to 2015. This is due tothe growth of the urban population and built-up areas. The study further underlined the importance of vegetation as greenareas show relatively fewer temperature variations throughout the years.

Living walls and Urban heat Island

A study has examined the implication of green infrastructure on enhanced microclimatic conditions in the Colombo Metropolitan area (CMA) by modeling with microclimatic software (Herath, et al., 2018). It shows a reduction of 1.86° C drop in temperature by using 50% of green walls on the plains of city. Unlike green roofs, green walls cancontrol the heated air mass trapped in the street canyon and the study further highlighted the importance of green wallsin urban infrastructure as a heat mitigating strategy is very successful as it can contribute to an effective temperature drop in microclimate. Therefore, wider vegetative surfaces can decrease air temperature by direct shading of surfaces,by restraining solar heat gain from evapotranspiration and converting solar radiation to latent heat. Moreover, they can reduce the building surface temperatures through the evapotranspiration process and increase adding moisture to the air from covering and shading building facades. This would achieve a higher energy saving and ensure optimum thermal conditions for city dwellers and occupants in Colombo Metropolitan Area.

A research series initiated by Rupasinghe and Halwathura, have carried out a field study implementing Vertical Greening Systems (VGS) in two administrative buildings in Colombo and Kandy to achieve the maximum benefit interms of thermal performances. Out of VGS types, the results of the study reveal that Living Walls are better in thermal performances where temperature recorded a maximum reduction of 10.16°C, 3.31°C and 2.11°C in external wall surface, internal wall surface and internal air temperature respectively (Rupasinghe & Halwathura, 2020). Further, a simulation study conducted on living walls adopting to buildings in the Colombo context signified a possible maximum internal temperature reduction of 4.89°C during the day. Moreover, by introducing living walls to the building façade shows a reduction of internal temperature which directly reduced the year-round energy consumption of the buildingby decreasing the cooling load which makes the building energy efficient. As Sri Lanka's energy consumption for space cooling accounts for more than 75% of electricity use in a typical building (Geekiyanage & Ramachandr, 2018), the adoptation of living walls to building facades helps in saving the country's total energy consumption.

It can be concluded that greenery or vegetation can influence the existing microclimatic condition in a city, can be used as a UHI mitigation strategy and reduce the cooling load in building energy consumption in Sri Lankan urban context. Furthermore, Herath et al. emphasized the importance of research studies which are required to assess the economicalinterpretation in terms of cost and maintenance to select the best suitable alternatives among different options for futurestudies (Herath, et al., 2018).

RESEARCH DESIGN AND METHODOLOGY LITERATURE REVIEW

The Comprehensive literature review will be carried out to understand the followings:

Following the research question and challenges, data will be collected on, mortar and brick properties, vegetation andgermination, irrigation systems, and structural properties through scientific literature reviews, manufacturers' catalogues or applicable books and interviewing experts in different fields, such as civil engineers, Landscape architects, agricultural specialists and other specialists who will be essential during the design stage. Interviews are focusing on unstructured, semi-structured and structured interviews on how to develop an eco-modular brick until thefinal product test.

Along with the preliminary study, data should be focused and gathered on undesired events of biological growth on buildings and structures which cause damage building materials. Data will be collected concentrating on the following factors addressed in the table 01:

Table 1: Collection of Data

Subject	Data
Construction materials	Materials -Aggregates, binder, additives
Mechanical properties	Mechanical resistance, porosity, viscosity, workability, comprehensive strength, waterproofing and PH values
Outdoor and indoor germination and perenniality	Test specimens
Microclimate and Exposure	Rainfall, temperature, humidity
Bio receptivity of materials	Sediment, humus, and moisture
Vegetation	Plant types (Vegetables, Fruits, Greens and herbs), rooting systems, seed substrate, depth, volume and weight of different plants, evapotranspiration rate, leaf area index
Irrigation technology	Water and nutrients supply, drainage
Accessibility	Monitoring and maintaining systems
cost	Materials, accessories, substrates, life cycle cost, manufacturing, and installation

DESIGN CONSIDERATIONS

By using the information gathered, a prototype modular eco brick will be designed and created to fulfill the demandfor green facades. The designed eco brick will respond to moisture transport behavior including, water absorption, moisture retention, permeability, and the related Characteristics. The Design development focuses on the main components as demonstrated in figure 6 in the modular brick, such as potting area and plant growth, pipeline for the Irrigation system, water-proofing layer, structural interlocking sections and water dripping area are the main concerns.

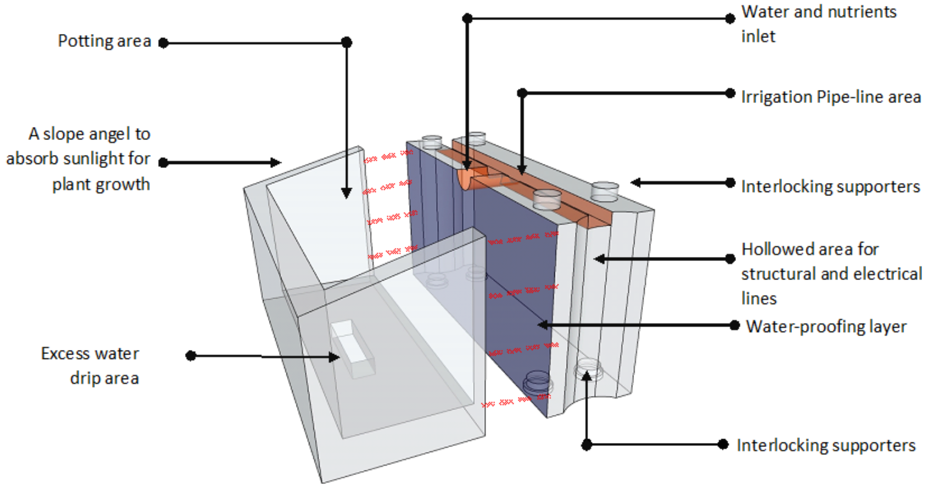

Figure 6: Design considerations

Then the effects of components (binder, aggregates, additives) on the physical and mechanical properties of the brick and mortar are assessed; following, the bio-receptivity of the mortars will be evaluated. As the requirements are posed, the mechanical strength and durability will be estimated and studied thoroughly. The brick-motor combinationsare to be tested in the following phase. Revised designs will be implemented in a small test group.

TESTING THE CONCEPT AND VALIDATION

A prototype module will be created, and the first trial will be taken in an indoor test room. Specimens will be tested(mechanical and physical strength) with designated SLS standards which require minimum compressive strength to ensure durability. Also, flexural tensile strength is an important design consideration for a modular brick which wouldbetter withstand harsh weather events.

After all design developments and mechanical tests, a specific type of binder/aggregate ratios will be selected in volume, the grain size distribution of the aggregate, the thickness, Gaps, and results of different minerals, which undergo significant expansion when heated, types of binders to be used, either alone or in combination will be finalized and standardized. Designs will be measured for the slump, density, and porosity.

A few sets of trials will be taken in Finally, outdoor experiments will be conducted for observations and developments. Weather and climate will be recorded during the test trials. Ambient temperature during both day and night, humidity levels, precipitation levels and rainfall patterns will be monitored. This prototype modular brick will be further improved to suit the demands of the residential, commercial and all sectors.

LIVING WALL CONSTRUCTION METHODOLOGY

By using the developed and finalized brick module, a mockup wall will be built vertically in an outdoor testing areafacing four cardinal orientations. The mockup wall will be 3m x 3m in height and width. An irrigation system will beinstalled, balanced, and functioned by using portable water. Plant selection has become a major factor which suits thetropical climate. Plant and substrate selection will be the next step of the study. Earth or compost, coconut fiber, humus, Rockwool mineral fibers or other substrates will be tested in different layers. During the integration of the bio-integrated modular façade, the use of water, air, moisture barriers, insulation properties, integration of primary structure, distribution of mechanical, electrical, and plumbing facilities and potential to resist lateral and shear forceswill be studied and developed for a better upshot.

The wall will be observed and monitored daily for about 3 to 4 months of timeframe. Time-lapse photography for data collection and records. Moreover, for analysis of plant development, substrate evolution, irrigation functioning, water consumption, water resistance, drainage challenges and durability and vulnerability of each module.

THE EXPERIMENTS ON DIFFERENT SPECIMENS.

To understand the strength performance with different combinations;

1. Trial and error basis application of different stabilizers and compare with cement. The mix will be selectedmaintaining different grade combinations. Gravel, sand, and cement are constant and varying in the use of water. Sample blocks will be tested (the strength and the durability).
2. Cast blocks and mold will be kept for 28 days for curing and to achieve maximum strength.
3. After 28 days testing will be carried out to check the strength.
4. Results will be compared with the wet and dry strength requirement for load-bearing walls.

5. From this, it can understand how the strength can be achieved with water and aggregate content.

MATERIALS AND MIX PROPORTIONS, DEVELOPMENT OF BEST COMPOSITION COMBINATION

a) The mix properties of cement and aggregates will be taken into consideration after confirming their abilityto develop the strength.
b) The trial mix will be used maintaining gravel, sand, and cement constant. And the composition of added mixtures will change according to the development of strength and other required properties mentioned inthe research proposal. Experiments with a water composition ratio of water will be tested on lab scale.
c) And the activity of water with a combination of aggregates will be studied in order to understand how thewater will react tocement composition

The design of the modular brick will focus on a hollowed type block having a hole in the middle of the open at bothsides. The total void area will be fixed into about 15% of the gross cross-sectional area. The voids can be filled with steel bars and concrete achieving high strength and earth-quick resistance. The air space provides good thermal insulation.

DURABILITY TEST AND WEATHER TESTING FOR THE MIXTURE DEVELOPED AND THE APPLICATIONS

a) The wall or the block work made of the above-mentioned mixture will be tested to measure itsdurability.
b) The durability will be measured by using simple weather testing of using cast walls exposed to free weather.
c) The durability of the castle yet wall will test using accelerated weather testing whereas the accelerated rainwill be poured into the wall and test the depth of the pit produced by the accelerated rain.
d) Possible fire testing (only the weight loss ratio after the exposure to the constant fire reproduced by thefurnace)

A list standard for testing cement blocks and we shall develop our methodology to measure the workability ofcement aggregate mixture. Not only sorptivity there are more than 12 standards that should be tested in quality. Following tests are conducted on the following stabilizer stabilized blocks/ bricks to determine their suitability for construction work.

- Absorption test

- Crushing strength test
- Hardness test
- Shape and size
- Color test
- Soundness test
- Structure of brick
- Presence of soluble salts (Efflorescence Test)

ABSORPTION TEST ON MODULAR BRICKS

An absorption test is conducted on the brick to find out the amount of moisture content absorbed by the brick under extremeconditions. In this test, sample dry bricks are taken and weighed. After weighing these bricks are placed in water withfull immersion for a period of 24 hours. Then weigh the wet brick and note down its value. The difference between dry and wet brick weights will give the amount of water absorption. For a good quality brick, the amount of water absorption should not exceed 20% of the weight of the dry brick.

CRUSHING STRENGTH OR COMPRESSIVE STRENGTH TEST ON BRICKS

The crushing strength of bricks is determined by placing the brick in a compression testing machine. After placing the brick in the compression testing machine, apply load on it until the brick breaks. Note down the value of the failure load and find out the crushing strength value of the brick. The minimum crushing strength of the brick is 3.50N/mm2. If it is less than 3.50 N/mm2,then it is not useful for construction purpose.

HARDNESS TEST ON BRICKS

A good brick should resist scratches against sharp things. So, for this test, a sharp tool or fingernail is used to makeascratch on brick. If there is no scratch impression on the brick then it is said to be hard brick.

SHAPE AND SIZE TEST ON BRICKS

The shape and size of bricks are a very important consideration. All bricks used for construction should be of the same size.To perform this test, select 20 bricks randomly from the brick group and stack them along its length, breadth and height and compare. So, if all bricks are similar in size, then they are qualified for construction work.

COLOR TEST OF BRICKS

A good brick should possess bright and uniform color throughout its body.

SOUNDNESS TEST OF BRICKS

The soundness test of bricks shows the nature of bricks against sudden impact. In this test, 2 bricks are chosen randomlyand struck with one another. The sound produced should be a clear bell-ringing sound and the brick should not break. Thenit is said to be good brick.

STRUCTURE OF BRICKS

To know the structure of a brick, pick one brick randomly from the group and break it. Observe the inner portion ofthebrick clearly. It should be free from lumps and homogeneous.

EFFLORESCENCE TEST ON BRICKS

A good quality brick should not contain any soluble salt in it. If soluble salts are there, then it will cause efflorescence on brick surfaces. To know the presence of soluble salts in a brick, placed it in a water bath for 24 hoursand dry it in shade. After drying, observe the brick surface thoroughly. If there are any white or grey color deposits, then it contains soluble salts and is not useful for construction.

DISCUSSION

Design and Development

Design and development of the vegetated modular brick unit to facades in building architecture where the masonryunit acts as a potting area for plants and is also structurally supported and interlocked as a component. The vegetated modular unit is designed to cater for a planting area, space for irrigation pipelines and outlets, and structural interlocking elements. The self-interlocking is achieved by using a shear key and lock mechanism in the modular unititself. The shape of the shear key is elemental as a nob shape where the complimentary lock is provided on the oppositeside of the brick (at the bottom of the brick). Load transfer is achieved by shear transfer and gravity. The block layeringcourses in away interlocked and overlapped each other. A separate corner unit will provide in the design. The overlapping of units helps in catering more sunlight to the vegetation. The curved open-ended facilitated reinforcement/conduit features at both sides of the unit.

Conducting or water and nutrient supply pipes are arranged along the hollowed space created by open-ended corners of interlocked units.

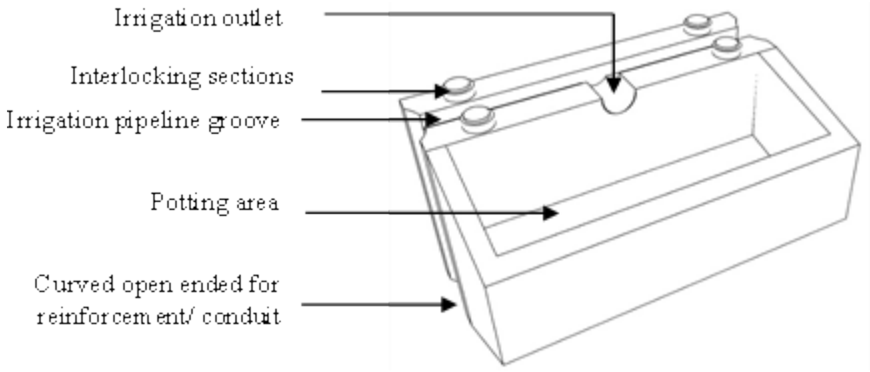

Figure 7: Perspective view of the modular brick

The groove at the face of the brick caters to water supply pipes extending in the horizontal direction and installed water pipe outlets for drip irrigation and at the central groove which falls to the potting area. A plurality of branch pipes connects the plant layers. A potting area with an angle of 15 degrees at the female face and 30 degrees at the male face is erected out from the masonry unit. The growing unit opens from the above and vegetation can be plantedin the unit.

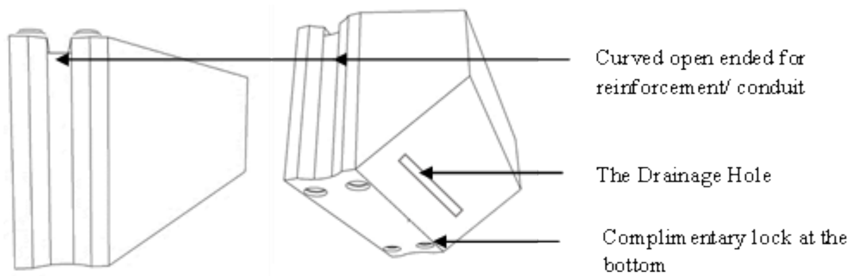

Figure 8: Side elevation and the perspective view from the bottom of the module

A drainage hole is provided at the bottom of the planting area. The water will be drained to the unit below enhancing the drip irrigation system. This designated drip line is provided with a light metal mesh with smaller squares to stop the erosion of soil from one unit to another. The waterproofing layer is applied main body of the unit. The moisture absorption is restricted for better structural durability.

The materials, aggregates, cement, and water are mixed in appropriate proportions and formed in the unit by using a designed mould.

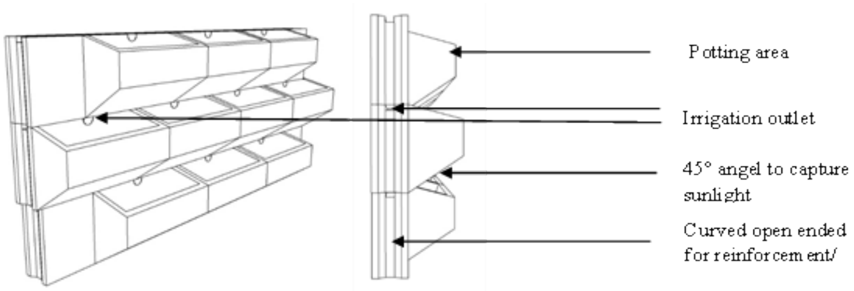

Figure 9: Perspective and side elevation of construction of a wall with interlocking vegetated modular brick

The invention overcomes the defects of the invention in the background art and creatively applies the vegetation tothe exterior/interior wall system of the building. This creates an effective construction scheme adopting a unique system design. Also, this solves the problems of construction, installation, water supply, power supply, irrigation, anddrainage of the vertical greening system. With this construction method, an environmentally friendly and energy- saving product can be manufactured.

Finally, it should be noted that: although the present invention has been described in detail concerning the foregoing embodiments, it will be apparent to those skilled in the art that modifications may be made to the embodiments or portions thereof without departing from the spirit and scope of the invention.

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