

Method for Making a Lighting System for Plant Growth and Viewing and A Lighting System

Field

- 5 The present invention relates to a method for making a lighting system for plant growth and viewing and a lighting system.

Background

- 10 Expenses associated with lighting for plant growth in indoor settings can be notably high. This is primarily due to the substantial amount of artificial light needed to substitute natural sunlight required for plant growth. These costs encompass both initial setup expenses, installation charges, and ongoing maintenance costs. Users often find themselves grappling with fluctuating electricity
- 15 costs influenced by varying global economic conditions. In such circumstances, justifying the sustainability of indoor greenery and the importance of fostering a harmonious relationship between humans, plants, and nature can be challenging.

Summary

- 20 According to an example of the present disclosure, there are provided a method for making a lighting system for plant growth and viewing, and a lighting system as claimed in the independent claims. Some optional features are defined in the dependent claims.

Brief Description of the Drawings

- 25 Examples in the present disclosure will be better understood and readily apparent to one skilled in the art from the following written description, by way of example only and in conjunction with the drawings, in which:

- 30 Fig. 1 shows a flowchart of a method for making a lighting system for plant growth and viewing according to an example of the present disclosure.
Fig. 2 shows a diagram for introducing 3 examples of lighting systems, namely planters A to C, for comparison.
- 35 Fig. 3A to 3C show examples of light beam shape, light beam luminosity (Lux) values and photosynthetic photon flux density (PPFD) values respectively of a light fixture according to an example of the present disclosure.
Fig. 4A shows a top view of a targeted area of greenery or plant bed according to an example of the present disclosure.
- 40 Fig. 4B shows a front view (length) of the targeted area of greenery or plant bed of Fig. 4A.
Fig. 4C shows a side view (width) of the targeted area of greenery or plant bed of Fig. 4A.
Fig. 5A shows a side view (width) of a set-up of a comparative example of a lighting system (i.e. planter A of Fig. 2).
Fig. 5B shows a front view (length) of the set-up of Fig. 5A.
- 45 Fig. 5C shows a schematic diagram of a top view of the set-up of Fig. 5A.
Fig. 5D and 5E show examples of light beam luminosity (Lux) values and photosynthetic photon flux density (PPFD) values respectively of the lighting system of Fig. 5A.
Fig. 6A shows a front view (length) of a set-up of an example of a lighting system of the present disclosure (i.e. planter B of Fig. 2).
- 50 Fig. 6B shows a schematic diagram of a top view of the set-up of Fig. 6A.

- Fig. 6C and 6D show examples of light beam luminosity (Lux) values and photosynthetic photon flux density (PPFD) values respectively of the lighting system of Fig. 6A.
- Fig. 7A shows a front view (length) of a set-up of an example of a lighting system of the present disclosure (i.e. planter C of Fig. 2).
- 5 Fig. 7B shows a side view (width) of the set-up of Fig. 7A.
- Fig. 7C and 7D show examples of time-averaged light beam luminosity (Lux) values and photosynthetic photon flux density (PPFD) values respectively of the lighting system of Fig. 7A.
- Fig. 8 shows a Unified Glare Rating (UGR) chart describing eye discomfort glare criteria.
- Fig. 9 shows reference numbers given to pots of plants in plant beds of Fig. 4A, 5B, 6A, and 7A.
- 10 Fig. 10A shows two graphs showing plant height measured on day 1 and day 57 respectively for planters A to C of Fig. 2.
- Fig. 10B shows two graphs showing plant diameter measured on day 1 and day 57 respectively for planters A to C of Fig. 2.
- Fig. 10C shows two graphs showing plant internode distance measured on day 1 and day 57 respectively for planters A to C of Fig. 2.
- 15 Fig. 10D shows two graphs showing plant leaves length measured on day 1 and day 57 respectively for planters A to C of Fig. 2.
- Fig. 10E shows two graphs showing plant leaves width measured on day 1 and day 57 respectively for planters A to C of Fig. 2.
- 20 Fig. 11A shows a front view and a side view of a set-up of a static lighting system according to an example of the present disclosure.
- Fig. 11B and 11C show examples of light beam luminosity (Lux) values and photosynthetic photon flux density (PPFD) values respectively of the lighting system of Fig. 11A.
- Fig. 12A shows a front view and a side view of a set-up of a dynamic lighting system according to an example of the present disclosure.
- 25 Fig. 12B shows an instantaneous capture of photosynthetic photon flux density (PPFD) values of the lighting system of Fig. 12A.
- Fig. 12C and 12D show examples of time-averaged light beam luminosity (Lux) values and photosynthetic photon flux density (PPFD) values respectively of the lighting system of Fig. 12A.
- 30 Fig. 13A to 13D show four different light source arrangement configurations in a light fixture that are configured according to examples of the present disclosure.
- Fig. 14A shows a side cross-sectional view of a light fixture with secondary optics according to an example of the present disclosure.
- Fig. 14B shows a side view of a light fixture for illustrating how 40 degrees anti-glare feature can be implemented according to an example of the present disclosure.
- 35 Fig. 15A to 15C shows three light fixtures with tiltable features that are configured according to examples of the present disclosure.
- Fig. 16A shows a linear motion light fixture configured according to an example of the present disclosure.
- 40 Fig. 16B to 16E show four oscillating motion light fixtures that are configured according to examples of the present disclosure.
- Fig. 16F and 16G show two rotating motion light assemblies that are configured according to examples of the present disclosure.

45 **Detailed description**

- Examples of the present disclosure relate to an innovative lighting solution offering more sustainable, intelligent, and efficient approach to meet growth requirements of plants, while simultaneously reducing the financial burdens associated with equipment procurement,
- 50 installation, maintenance, and recurring electricity expenses. Remarkably, the proposed approach achieves all these without compromising on plant growth and environmental advantages of having

thriving plants coexist with people indoors or in sheltered places where plants require artificial lighting in addition to sunlight to grow. In essence, the proposed approach is not merely about optimizing resources, it is about maximizing energy efficiency.

- 5 Specifically, the innovative lighting solution comprises a method of making an optimum lighting system and the lighting system. By adopting the innovative lighting solution, users can significantly cut down on their initial equipment outlays, decreasing the financial barriers to entry for indoor/sheltered greenery projects. The installation process becomes more cost-effective, and reduced need for maintenance contributes to long-term savings. More importantly, the innovative
10 lighting solution minimizes recurring electricity costs and energy consumption, making indoor greenery financially viable even in the face of fluctuating energy prices.

- Ultimately, the proposed approach fosters a sustainable and intelligent method of cultivating indoor/sheltered greenery that not only benefits plants but also aligns with ecological and
15 economic considerations. It can achieve a harmonious symbiotic coexistence between humans and nature, which can promote the well-being of both while simultaneously being mindful of resource utilization and energy efficiency.

- The optimum lighting system aims to be a scalable intelligent lighting system designed to
20 maximize energy and cost savings by precisely combining calculated plant growth light spectrums, and calibrated to meet specific requirements of targeted coverage, daily light integral (DLI), photoperiod and desired plant response. In some examples of the optimum lighting system, strategic light distribution is achieved through mechanical dynamic adjustments in position at the correct photosynthetic photon flux density (PPFD) intensity and speed. PPFD measures the
25 amount of Photosynthetic Active Radiation (PAR) that actually arrives at the plant. Typically, the wavelengths that make up the PAR are between 400nm and 700nm, which are used for photosynthesis.

- A light source in the present disclosure can refer to a high-power Light Emitting Diode (LED), a
30 plurality of high-power or normal power LEDs, a bulb and/or lamp. A light fixture in the present disclosure can contain one or more of the light source.

- Specifically, conventional lighting systems cannot be used to create a sheltered or indoors
35 environment for harmonious symbiotic coexistence between humans and nature because of the following reasons.

- Conventional artificial plant growth lighting is not human centric, for instance, not having Colour
Rendering Index (CRI) of greater than 90 and R9 colour rendering value (R9) of greater than 90.
40 They are coloured (blue and red lights), which is useful for plant growth but not pleasant for viewing by people. Blue Light Emitting Diodes (LED), which emits light harmful to human eyes, may be used. People may find plant growth lighting glaring and uncomfortable.

- On the other hand, conventional human centric lightings such as architectural lights are available
45 for use in human spaces. However, they all lack the light spectrum and efficacy for plant growth. They are certainly not designed to provide the sunlight replacement intensity required for plant growth.

- In existing plant growth lighting systems, the plants are sometimes moved around between well
lighted and less lighted areas to ensure that all of them receive sufficient light to grow consistently.
50 The situation that there will be plants that grow significantly better or poorer than others should be prevented. However, moving plants around is not scalable, labour intensive and usually only

for potted plants. It is certainly not for in-ground plants or trees, which one would consider in an indoor or sheltered garden or display. Movable lights may be considered as a solution. However, conventional lighting systems that are movable are not suitable. For instance, stage lightings for stage performances may be movable but they are not designed for plant growth, usually bulky and glaring. Most stage lightings are mounted at a fixed location and movements are limited to rotation about the same fixed location. They are typically not capable of linear movement, which can allow movement of light sources in an area to provide lighting for plant growth in the area.

Furthermore, it is challenging to determine the movement parameters of the light sources that is optimal for plant growth. For instance, it is hard to determine the movement speed, cycling time (e.g. a cycle refers to moving from a point A back to the same point A), and set the right light intensity for plant growth. Movement speed is important because fast light movements are not suitable in human spaces. If not set up properly, light from moving light sources can cause discomfort to humans.

There are other considerations besides movement speed. Simply setting slow light movements is not enough. The light needs to have the right light spectrum and intensity for growing plants. Current standard light intensity controls for dimming (or strobing) cannot optimize light output utilization for plant growth as they are not designed for doing so.

In terms of achieving optimal light distribution, some current lighting systems make use of reflectors to reflect light from light sources to spots that are harder to reach by the light from the light sources. However, reflectors are inefficient for plant growth usage and not dynamic i.e. they are mostly fixed and cannot be moved around. Optical spread lenses and light diffusers are available to spread emitted light, however, if not set up properly, it may result in loss of light intensity and more light fixtures would be required to install more light sources to make up for the light intensity loss. This would be not power efficient.

In some conventional lighting systems, light distribution and intensity for plant growth is achieved by setting up light sources at close proximity to the plants. For example, only 3 to 6 inches (7.62 cm to 15.24 cm) away from the plants. Although this is effective for plant growth directly below the light sources, the light fixtures comprising the light sources obstruct the plants and humans cannot view and/or appreciate the greenery of the plants. Furthermore, LED lifespan, may be compromised when exposed at 7.62 cm to 15.24 cm distance from water, moisture and humidity. Due to close light source distances (for example, 3 to 6 inches), more light fixtures must be added to light up dark spots and ensure sufficient coverage. More light fixtures means increased energy/power utilization. There is an option to use off-the-shelf high intensity light sources, however, this leads to higher power consumption. Such off-the-shelf high intensity light source is also typically unable to spread and distribute light. The high intensity can cause undesirable plant elongation and uneven growth. Furthermore, use of overhead lights is common for plant growth. However, such overhead lights are not angled for good light distribution and plant viewing. Moreover, current lighting systems are not efficient in the sense that they have light colour controls that affect light intensity during colour tuning, reducing the overall efficiency and efficacy. For instance, light intensity has to be reduced to mix and tune light colour.

The innovative lighting solution can be said to be a function of the following 4 factors, working in synergy.

1. Engineered Plant Growth and Human Centric Light Spectrums

A wide range of plant growth light spectrums is developed for different and many applications, specifically in 3 categories as follows.

a) Human Centric Plant Growth Light Spectrum

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Light sources configured to have human centric plant growth light spectrum would have overall white output for masking coloured light used for plant growth so as to produce overall light output that is sufficiently pleasant for human viewing. The light spectrum should meet requirements of Colour Rendering Index (CRI) of greater than 90 (which can bring out the natural colours of plants and flowers) and R9 colour rendering value (R9) of greater than 90. The lighting system should pass photobiological safety tests based on standards set by, for instance, International Electrotechnical Commission (IEC) or similar institutions.

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Secondary optics (lenses, reflectors, and/or diffusers) may be used with one or more light sources to shape, spread or distribute light as desired. Fig. 14A shows a side cross-sectional schematic view of a light fixture 1400 comprising an LED 1402 and secondary optics 1404. The secondary optics 1404 shape the light emitted by the LED 1402 to project a pre-determined light beam angle 1406. LEDs is a preferred choice. Different types of LEDs may be used. In some cases, only high-power LEDs are used to provide the required light intensity. Low Power LEDs refers to LEDs with driving current of about 20 to 50mA, mid Power LEDs have driving current of about 65 to 300mA and high-power LEDs have driving current of about 350 to 1500mA.

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The light fixture 1400 can be configured to be stationary to provide top-down light projection. In such configuration, it is suitable for projecting light at horizontally disposed greenery areas comprising planters, a garden, potted plants, one or more tree canopies, etc.

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A general rule of 40 degrees or more cut off angle should be implemented for the proposed light fixture to prevent glare to human eyes from the light sources. Such cut off angle can be achieved by configuring light fixtures comprising the light sources to have shields or shielding members to shield the light emitted from the light sources. Fig. 14B shows a side schematic view of the light fixture 1400 of Fig. 14A emitting light 1408 with the 40-degrees cut off feature. The emitted light 1408 does not spread wider than 40 degrees from a horizontal axis 1410 that is perpendicular to the vertical central axis of light emission. Such vertical central axis of light emission is the main optical path and primary direction of light emission of the light source.

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The light from the light sources should also preferably have a Unified Glare Rating (UGR) of 19 or less. Fig. 8 shows a chart of different UGR ranging from 10 to 28 and the corresponding discomfort glare criterion. Lighting with UGR of 19 or less is deemed as just acceptable to human eyes. The formula of UGR is as follows.

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$$UGR = 8 \log_{10} \left[\frac{0.25}{L_b} \cdot \sum \frac{L_i^2 \omega_i}{p^2} \right]$$

where

8: Constant factor 8 for a value range between 10 and 30;

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Σ : 'Total' sign causing the addition of the glare effect of each visible luminaire;

log: Common logarithm taking into account the logarithmic perception of brightness;

L_b : Background luminance (determines the state of adaptation of the eye);

L_i : Average luminance of each individual luminaire;

ω : Solid angle of the illuminating parts of the luminaire from the observer's position as a measure for the size of the glare light source; and

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p: Guth index as a measure of the position of the luminaire in relation to the direction of view of the observer.

- 5 For example, if the proposed light fixture is configured such that the variables listed in the formula of UGR is well controlled, the UGR value can be lowered, making it ideal for spaces requiring high visual comfort like places of assembly, health care premises, etc., which should have UGR value of less than 16.

b) Coloured Growth Spectrum

- 10 The proposed lighting system is growth focused and should provide enough coloured light to support plant growth such as light from the red and blue light wavelengths. While it is necessary for the proposed lighting system to provide a blend of light that appears white and is pleasant for viewing and sufficient for plant growth, the proposed lighting system may have tuning features or
- 15 pre-sets to provide only or predominantly coloured plant growth light during predetermined periods of time so as to provide a boost for plant growth and switch off the white light to use less energy. For instance, most indoor or sheltered places would have little or no people at night and light for pleasant viewing is not required. Hence, the proposed lighting system may be configured to switch off white light and switch on only red and/or blue light, which are optimal for plant growth
- 20 at night or to make up for insufficient PPFD / Daily Light Integral (DLI) due to lower wattage fixtures selected to save energy.

c) Horti-tainment Growth Spectrums: Dynamic

- 25 "Horti-tainment" is a created word for providing entertainment through ways involving flora/plants. To the proposed lighting system, it means providing light for plant growth and to provide some form of entertainment as well. For example, instead of providing white light to mask coloured light to achieve pleasant viewing all the time, the proposed lighting system may be configured to provide a light show with entertainment value at pre-determined time periods. For instance, such
- 30 light show may shine on the plants using only red light for one moment, switch to only blue light for another moment, switch to white light and/or other coloured light in another moment. There are 16.8 million colours to select from using a DMX system and the energy used for human enjoyment is benefiting the plants at the same time. If the proposed lighting system has movable light sources, more can be done to heighten the entertainment value of the light show. Parameters that can be adjusted for the light show are, light colour, light intensity, light source movement path
- 35 and speed (for non-static lighting system),

40 The proposed lighting system can make use of one or more of the above-mentioned 3 categories of light spectrum a), b) and c) in a single light fixture to suit different applications and preferences.

2. Strategic Dynamic Light Distribution (SDLD) Technique

- 45 The proposed lighting system is made using a Strategic Dynamic Light Distribution (SDLD) Technique. The light sources can be arranged in a linear, spherical or circular pattern, and may be made to oscillate and/or move.

3. Correct/Desired PPFD Intensity and Beam Shaping

- 50 Importantly, the correct/desired PPFD Intensity required for the plants to be grown has to be used and the light beams of the light sources have to be shaped appropriately to provide the right intensity as needed. To cater for different scales or sizes of plant set-ups or plant displays (i.e. the

plants to shine light on), different light fixtures of different wattages, for instance from 6W to 128W, may be used in combination with different beam angles of the light sources (covering a beam from 4D optical lens, wide beam, elliptical beam etc.), for precise light distribution and right light displacement from light sources placed at predetermined distances away from the plant set-up.

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4. Right Speed

In the case that movable light sources are implemented, the right speed of movement of the light sources is important. For instance, the light sources can be moved at a speed of 0.001mm – 800mm per second. The proposed lighting system should have a modular design for scalability and preferably made to enable “plug and play”. A processor and/or controller and human-machine interface can be provided to enable the lighting system to be adjustable to adjust light settings and/or movement settings if movable light sources are implemented.

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15 Movement speed settings are dependent on fixture wattage, beam shape and plant species to be grown. More examples of preferred movement speed presets and general guidelines on how they can be used are as follow.

Preset 1: 0.001 to 200 mm / sec; slow speed generally for plants requiring more light penetration, larger beam spread, and/or higher wattage/intensity beam.

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Preset 2: 200 to 500 mm / sec; medium speed generally for plants requiring medium light penetration, medium size beam spread, and/or medium wattage/intensity beam.

Preset 3: 500 to 800 mm / sec; higher speed generally for plants requiring less light penetration, smaller beam spread, and/or lower wattage/intensity beam.

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In some cases, the movement speed can be configured to be different for different areas of a plant area (e.g. faster movement for some areas and slower movement for some areas), and/or different movement speed during different life cycles of the plants.

An example of a proposed method for making a lighting system for plant growth and viewing according to the present disclosure is as follows.

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With reference to Fig. 1, at step 102, parameters of a targeted area of greenery to be lighted up for plant growth and viewing are obtained. The parameters should include at least one or more plants to grow and size of an area provided for placing the one or more plants to be grown. The parameters may be inputted by a client wanting to set up such area of greenery or plant display and/or jointly or solely inputted by a maker of the lighting system.

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The parameters may include designated areas where light fixtures can be mounted and/or cannot be mounted, the distance between the light source and the planting area, the heights of the plants, the height of the plant display area (e.g. the height of a vertical wall plant display), and any restriction/requirement to light fixture mounting such as the light fixtures must be recessed into a ceiling. The parameters may also include the allowed power budget and the preferred light spectrum or combination, which may be selected from the 3 categories a), b) and c) of proposed light spectrums described earlier.

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Examples of parameter inputs are plant type, preferred PPFD, plant size in height and/or diameter, density of leaves, size and shape of targeted area of greenery in length, width and height, etc. The parameter inputs may further include available location for mounting light fixtures. Shape of the targeted area of greenery may be elongate, straight, curved, circular, horizontal and/or vertical.

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The shape will determine the light fixtures to use.

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At a step 104, the targeted PPFD required to grow the plants is obtained, if PPFD data is not provided at step 102. In the case where there are different plants to be grown, the average PPFD may be determined. The wattage of the light sources required to produce the desired PPFD is determined. The wattage can be sized up depending on the distance between the light source and the plant and the plant species of the plant display inputted at step 102 (i.e. higher wattage used for longer farther distances and plants that would normally require more sunlight when grown outdoors). A formula, reference table, and/or equation may be determined and used to determine light fixture Wattage. For instance, the formula, reference table, and/or equation may define a relationship between PPFD intensity and a particular distance of the light source away from the plant display, etc.

To make the proposed lighting system modular and scalable, light modules of specific wattage can be created. The right number of the light modules can be used for different scales of plant displays. For example, the wattage of the light modules may range from 6W to 128W and each module may be made to support specific wattage such as 6W, 8W, 10W, 12W, 14W, 18W, ... and so on, which is in increments of 2W.

A simulation software may be used to estimate and simulate PPFD intensity over the targeted area of greenery and the estimated/simulated results can be checked to ensure that there is sufficient PPFD intensity on the targeted area for plant growth. Lighting heat (or contour) maps may be generated to gauge light distribution and spread. Correction or conversion factors associated with measurements of pre-determined light spectrums can be pre-calculated and used to enable quick decisions on the wattage and light sources to use for a target area of greenery. A luminous flux per unit area (Lux) to PPFD conversion factor can be used to work out the lux required for a desired PPFD and the Lux value can determine the wattage and light sources to use. For example, full sunlight has PPFD value of $2000 \mu\text{mol m}^{-2} \text{s}^{-1}$ or 108,000 Lux ($2000 * 54$).

Examples of PPFD Range in $\mu\text{mol m}^{-2} \text{s}^{-1}$ required for plants to be grown indoors or under shelter are as follow.

- Ground Covers: 30 to 50.
- Shrubs: 50 to 80.
- Small Trees: 100 to 150
- Big Trees: 200 to 250
- Green vertical walls: 40 to 60
- Green Columns: 40 to 60

For example, the simulation software may make use of Illuminating Engineering Society (IES) files from the IES library to describe how light from a lamp is distributed in a room. New files may be created after making real-world lighting measurements to see the effects from such real-world measurements. Such new files constitute part of the data to be used for simulation. This data is provided by many manufacturers so that lighting designers can realistically simulate how a project will look when a specific light source is used. The lighting effects that can be simulated include use of different lighting wattages, different light beam angles, linear and circular arrangements of light sources within a light fixture, use of different types of light fixtures etc. The simulation can help to tell how good or bad a lighting system is performing and can help in the optimisation or tuning of the alignment, movement (for dynamic system), and/or tilting of the light fixtures to achieve best PPFD coverage.

At step 102, if it is gathered that there is some sunlight contribution for the targeted area of greenery, for example PPFD of $10 \mu\text{mol m}^{-2} \text{s}^{-1}$ (10PPFD), then 10PPFD can be deducted from

the the desired or targeted PPFD value to be determined, provided the 10PPFD from sunlight is contributed for at least 6 hours.

- Light source to plant distance (i.e. light source to plant canopy) has to be considered. Light travels according to inverse square law such that from a light emitting point, light loses intensity by the inverse square of the distance it travels. For example, the distance range can be between 700 mm to 18 meters, or preferably, 1 m to 15 m. Specifically, a light throw of 700 mm to 5 meters is preferably the minimum distance range between light source and plant (or green surface) to provide good visibility of the plants for pleasant human viewing. A preferred medium distance range for longer light throw is about 5 to 10 meters, which can be for light fixtures mounted on a high ceiling, double volume ceiling or triple volume ceiling. A preferred longest distance range is to throw light for about 10 to 18 meters. Such long distance range can be provided depending on the situation at the site to install the lighting system. For example, such long distances may be required for mounting of light fixtures on very high ceilings such as in atriums.
- At step 106, secondary lenses and/or fixture design are configured and/or adjusted according to the parameters inputted at step 102 and the PPFD requirements obtained at step 104. The required light fixture beam shaping is done to meet the PPFD intensity requirement obtained at step 104 and to provide the light area coverage required at a provided height (i.e. distance from light source to plants) based on parameters inputted at step 102. Preferably, secondary lenses are used to enhance intensity and control coverage. Fixture beam shaping is used to redirect spillage and control the coverage to minimize loss and maximize intensity. The beam shape can be formed using 4D optical lenses, wide beam lenses, and/or elliptical beam lenses to provide the right light distribution. The Ingress Protection rating of the light sources can be IP20, IP65 and IP67, depending on location of the light fixtures, so as to protect them against wet or damp environment.
- The secondary optics (lenses, reflectors, and/or diffusers) of the proposed light fixture can be selected to enable light to emit at different angles. The angles determine how the light is to be distributed in the targeted plant growing area or space. The light fixture can be configured to have light output at symmetrical angles, for instance, 4° (i.e. covers light beam angle of 2° on each side of central optical axis, $2 \times 2 = 4$ degrees), 5°, 8°, 10°, 16°, 18°, 20°, 29°, 39°, 42°, 44°, and/or 61° i.e. the light is distributed symmetrically or evenly in all directions from the center of the light fixture. The light fixture can also be configured to have light output asymmetrically such as 12° x 54° (i.e. 6 degrees angle on one side of central optical axis and 27 degrees on other side of the central optical axis) and 10° x 45° and distribute light unevenly to cover a wider area in one direction compared to another direction. The degrees, 12° x 54° and 10° x 45°, listed represent the angles of light spread in two different directions, creating an elongated light pattern. Secondary optics are required for long throw and light beam control. Using the secondary optics provides lighting control in contrast to a flood light where the light reaches everywhere and not intensified nor redirected as needed.
- The light fixtures to use can be arranged in a line, in a ring, following contours, fitted inside a structure etc. The mounting options for light fixtures include ceiling surface, pendant light mount (light source suspending from top), recessed ceiling surface, wall mount, pole mount, bollard mount, etc. Light angle has to be considered. For instance, light from light fixtures mounted on pole or bollards would reach plants from a side angle. The light fixtures should be made for ease of installation and maintenance. For instance, to provide frontal access for easy adjustment and replacement of LEDs or light bulbs.

A database comprising predetermined information of fixture types to cater for most common distances, angles, and plant types can be created. Such database can be referred to find out which light fixture is best for different mounting options. Such database can be used in conjunction or used to train an Artificial Intelligence apparatus or system to predict or prescribe fixture types, light to plant distance, angles etc., based on the entered parameters at step 102.

At step 108, the desired plant growth light spectrum (in short "growth spectrum") is configured and/or adjusted according to the parameters inputted at step 102 and the PPFD requirements obtained at step 104. A plurality of pre-formulated plant growth light spectrums is configured with the necessary wavelengths Blue/Red/Far-Red (B/R/FR) ratios required for plant growth that is uniquely mixed, and which the coloured light is masked to provide a visible output of whites (white light). The resultant white light can have, for example, Correlated Colour Temperature (CCT) of 2400K, 2700K, 3100K, or 3800K, which is for pleasant light viewing. The coloured light output may have CCT of 1850K and the light source may be configured to be colour changing.

The desired plant growth light spectrum can be selected from the plurality of pre-formulated plant growth light spectrums to match with interior designs of the environment of the targeted area of greenery. In the present disclosure, Red and Far-Red wavelengths are deemed as Red light. The pre-formulated growth spectrums can be configured based on the 3 categories described earlier and can involve tailored configurations of dynamic movements, dimming, changing of colour, changing of Correlated Colour Temperature (CCT), and creating a light show. Preferably, the proposed lighting system should have a processor or a controller configured to have adjustable White / Coloured / Tuneable options to aid such configurations. Tuneable options refer to programmable options to adjust dynamic movements, dimming, changing colour, changing Correlated Colour Temperature (CCT), and/or creating a light show.

Specifically, the plant light growth spectrum can be based on blue and red light wavelengths. In addition to plant growth lighting, it can provide white light outputs to match with or enhance ambient light. The proposed lighting system may be configured to have tuneable White CCT range of 2000K to 5400K. Examples of pre-determined selectable white light output options are as follow:

- a) 2400K CCT; white output; CRI > 90; and R9 > 90
- b) 2700K CCT; white output; CRI > 90; and R9 > 90
- c) 3100K CCT; white output; CRI > 90; and R9 > 90
- d) 3800K CCT; white output; CRI > 90; and R9 > 90

The abovementioned a) to d) can be configured as two or more selectable channels to be switched as desired within the same light fixture.

CRI is a measurement of how natural colours render under an artificial white light source when compared with sunlight. The higher the better, preferably greater than 90. Under low CRI light, items and colours may look flat, washed-out, desaturated, drab, and at times unidentifiable. Having low CRI will make the lighted plants look unappealing.

The wattage of each proposed light fixture can be configured in increments of 16W, starting from 16W, 32W, and going up to 144W. A lower wattage version of the light fixture of 6W can also be provided as required.

The abovementioned white light outputs are mixed with coloured light outputs with high PPFD output and the right concentration of Blue and Red wavelengths. The abovementioned a) to d) plant growth light spectrums are preformulated for both plant growth and plant viewing, requiring no further equipment to tune or to adjust the light frequencies or wavelengths. These plant growth light spectrums are engineered to optimize and to reduce unnecessary time for guess work, self

experiments, control systems, cabling, labour and costs. For requirements beyond the pre-determined selectable white output options, the formulation can be adjusted to suit the desired output.

- 5 Specific algorithms can be used in conjunction with the processor or controller described in the present disclosure to adjust the lighting based on data obtained, desired outcomes, etc. that are specific to the plant species to be grown. Based on the data, the lighting system may be configured to set different light intensity, frequency and/or wavelength during the life cycle of the plants to be grown so that the desired outcomes are met. Varying the frequency and/or wavelength
- 10 appropriately can change the way in which the plant grows or reacts to the light and can have an effect on the overall health and product of the plants to be grown. As an example, the light power (intensity, frequency, and/or wavelength) can be varied for different stages of the plant's growth from a low level at the beginning of a plant growth cycle to higher increased levels as the plant grows. This can be characterized as a light power curve (in a graph) that grows with the plant.
- 15 In case of an entire garden, planter, and/or green wall (i.e. vertical plant wall), which can easily have 2000 or more plants, it is not possible to target every individual plant. At times, additional light focus and booster lighting (i.e. providing extra lighting hours at targeted spots) can be programmed to shine at identified areas of flowering, edibles or different plant species requiring significantly different PPFD levels. For example, booster lighting can be coloured light only and
- 20 can be provided at hours which will not disrupt human activities (e.g. at night).

Data gathered from plant growth, fixture positioning, light intensity and coverage area can be used for reducing power consumption and cost in similar lighting system projects. Hence, a standard light assembly or system that can be optimized and useful for a consistent and repeatable result.

- 25 The light fixture may be configured to have colour changing capabilities since coloured lights (for example, B, R, W/B and W/R in Fig. 13A to 13D) are present in the light fixture. An appropriate light control system, its processor or controller and the right circuitries on a Printed Circuit Board of the system should be provided to provide different colours and allow their intensities to be adjusted and mixed. For instance, 16.8 million colours may be provided like in the case of entertainment lighting but it has to include light wavelengths meant for plant growth.
- 30

- With regard to light intensity, an appropriate programmable analogue or digital controller (e.g. for 0 to 10 Volts, DMX, DALI, Casambi, Wireless etc.) may be used for dimming and scene control and create light shows. Such controls are more for human comfort and entertainment and for power savings (e.g. dim or off lights at night). Such controllers may be programmed to create different ambient effects at different times of the day. Light intensity may be controlled to create different scenes as required such as welcoming atmosphere, vibrant atmosphere, formal meeting atmosphere, etc. If dynamic light fixtures are used, light shows can be created with the movable light sources in mind. Glare control can be applied internally i.e. pre-set for each light fixture, for instance, to achieve UGR of 19 or less. Lower UGR means less glare to humans and is preferred.
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- 40

- The lighting system may further include one or more sensors such as oxygen sensor, humidity sensor, temperature sensor, proximity sensor, movement sensor, etc. Such sensors may be used to trigger different light shows, scenes, light intensity, attention and/or mimic outdoor light condition
- 45

- With regard to the database mentioned above, each selectable plant growth light spectrum created and stored in the database can have its own conversion factor to Lux. Each beam angle should also have another conversion factor to Lux. The conversion factors can be determined and recorded for individual measurements at various distances away from each light source, for
- 50

instance, at 700mm, 800mm, 1m, 1.2m, 1.5m, 1.8m, 2m, 3m, 4m, and 5m. An example of sunlight lux to PPFD conversion factor is 54. With the database containing conversion factors, a lighting calculator can be provided for use in conjunction with the database to help to obtain Lux and/or PPFD values across an entire targeted area, be it a garden or a planter or a green wall etc.

- The processor or controller of the proposed lighting system may be configured to:
- switch on or off the system;
 - set a timer for selected, programmed or tuned lighting to be switched on, wherein said timer can be configured to provide lighting according to time of day and/or best suited for a predetermined life cycle of plant growth;
 - dim or brighten lighting as desired;
 - enable mixing of CCT to achieve desired light output (e.g. change in colour temperature to mimic dusk to dawn);
 - enable mixing of plant growth light spectrums to provide coloured plant growth light spectrum for boosting plant growth during specified time (e.g. white output plant growth light spectrum during working hours and coloured plant growth light spectrum after working hours);
 - enable mixing of colours for lighting scenes and/or light shows etc.; allow lighting scenes (to suit certain mood and to create attraction) and/or light shows to be displayed for commercial value;
 - receive feedback from one or more sensors as described in the present disclosure to trigger actions (e.g. detect that it is night time, detect a condition to create different lighting scenes or to display a light show, etc.);
 - adjust light frequency and/or wavelength as desired; and/or
 - control movement of light fixtures in the case that dynamic light fixture is implemented.

The processor or controller may be controlled via a remote controller, via a remote server, and/or a connected computer (e.g. desktop, tablet, or laptop computer) or connected smart device (e.g. a smart phone). A mobile application may be provided to control the lighting system. It is an advantage that saves cost to have both plant growth lights and general lighting for comfortable human use, and optionally, entertainment lighting, all in one lighting system.

At a step 110, the secondary lenses and/or fixture design determined at step 106 and the desired plant growth light spectrum determined at step 108 can be refined and optimized. A computer simulation can be done to facilitate such optimization. The simulation should be based on the given fixture location and height provided at step 102. The optimization can control and prevent wasted energy and spills caused by incorrect light fixture configuration and positioning.

At a step 112, calculations, in particular, for cost savings and to maximise light output, are done to ensure that the proposed lighting solution maximizes efficiency and reduces energy. This can be part of the optimization process. For example, the cost savings for using dynamic fixtures over static fixtures can be calculated and considered.

The proposed lighting system can have one or more static fixtures, one or more dynamic fixtures, or both. Generally, most of the time, for the same application, static fixtures would require higher quantities than dynamic fixtures. Therefore, having dynamic fixtures as opposed to only static fixtures can save on fixture, installation, energy consumption and energy cost. Dynamic fixtures provide immediate upfront investment and recurring cost savings. Dynamic fixtures can involve linear movements, rotation, and/or oscillation. The implementation of dynamic fixtures involves the steps of, calculating and determining the required light displacement, dynamic dimensions, movement speed of light sources, photoperiod, cycling and more. The purpose is to cover the

target coverage area and provide the required intensity from a given distance. The average light exposure provided to different parts of the target area should be considered. The average light exposure should provide enough light for plant growth.

- 5 More details on the dynamic fixture are as follow. It is implemented via a strategic dynamic light distribution (SDLD) technique. SDLD movements can include linear motion, rotation motion, and/or oscillation motion, and the motions can have preset time duration. Parameters such as planter type, plant growth surface (vertical wall / horizontal planter), dimensions and contours, collectively giving the PPFD required, and improving uniformity with time-averaged (over a motion
10 cycle).

Using Motors in combination with moving mechanism controlled by Maerich software to set the following parameters (where applicable): 1) Displacement; 2) Tilt angle; 3) Arc distances; 4) Time; 5) Speed; 6) Start / Stop / Return; and 7) Cycle.

- 15 At a step 114, following the calculations at step 112, light intensity is maximised at the level of power consumption of the light fixtures selected to be used so as to achieve as little number of light fixtures as possible.

- 20 At a step 116, the proposed lighting system is assembled from pre-set or prescribed components. For instance, the processor or controller of the proposed lighting system should be pre-programmed to enable Plug and Play. To achieve this, the light fixtures should be made up of modules and allow easy connection to one another in terms of hardware and software. Regardless of the number of the light fixtures being connected up, they should be controllable via
25 the processor or controller. There can be an option to link up with an existing lighting control system available on-site. In addition to the considerations mentioned above, a user can also consider the light fixture housing type and finishes, recessed, surface mounted, suspended, attached to a pole etc., Ingress Protection (IP) rating and accessories. Pre-set or prescribed components should be readily available for a user or client to select.

- 30 In addition to one or more processors or controllers for control, the proposed lighting system may be connectable to a display for showing a graphical user interface for user control, programming and/or setting. Such display may be the display of a connected computer (e.g. desktop, tablet, or laptop computer) or connected smart device (e.g. a smart phone). The display may be a touch
35 screen display. A plurality of user interfaces and/or a remote controller may have for instance, buttons, knobs, switches etc. provided for control. In the case of use of one or more dynamic light fixtures, one or more motor or engine are provided to drive its moving parts. The required mechanical guide rails, gears, pulleys, rollers, etc. are provided as well for dynamic light fixtures. A power supply for the lighting system can be the Alternating Current mains and/or portable power supply such as a generator or battery. The lighting system also includes wiring/cables and other
40 required electrical components/equipment. The one or more processors or controllers may be connected wirelessly or in a wired manner to a central control system (e.g. central server) allowing each processor or controller to be controlled centrally. Data pertaining to the lighting system may be collected and viewed centrally. In this case, the required data communication transceivers for connection to the processor or controller are provided to enable, for example, data communication
45 via WiFi, Wide Area Network (WAN), telecommunication network (3G, 4G, 5G etc.) or the like.

In summary, the product design flow of the proposed lighting system is as follows.

- 50 1. Set a targeted area of greenery in the product design.
2. Set a PPFD range to ensure the plants grow well in the targeted area.
3. Set a mounting height in the product design.

4. If possible, provide 2-3 product design set-up -options for consideration and selection. Only one option will be implemented.
5. The product design should be scalable and stackable.
6. Fix the light fixture Wattage. The Wattage is related to the PPFD intensity at the provided height.
- 5 7. Fix the light fixture beam shape and spread. This is related to PPFD intensity and Coverage at the provided height. Secondary lenses should be used to enhance light intensity and control light area coverage. Light fixture shaping is done to direct and control the light coverage to minimize energy loss.
8. Fix the option for the product design set-up .
- 10 9. In the case that dynamic fixtures are used, a technique to implement the dynamic fixtures has to be determined. For instance, the required dynamic dimensions, light source movement speed, and/or light source cycling have to be fixed for providing sufficient light area coverage and light intensity at a given distance.
10. The light intensity of the proposed lighting system should be maximised according to the power consumption of the Light fixture so as to reduce the number of light fixtures used to as little as possible.
- 15 11. Make Calculations and ensure that the resultant lighting system would maximize efficiency and reduce energy consumption. For instance, the cost for Static light fixture should be compared with Dynamic light fixtures and a decision should be made on whether dynamic and/or static light fixtures should be implemented. A dynamic light fixture basically has one or more light sources that is movable, for instance, by a motor.
- 20 12. The proposed light fixtures should be made up of modules that can achieve Plug and Play. That is, the modules can be connected or disconnected as required and preferably controlled via the same software or firmware installed in one or more processors or controllers. In terms of appearances, the light fixtures may be designed with options such as options of finishes and include options for adding a decorative shade to compliment interior design of the environment of the targeted area of greenery to be lighted.
- 25
- 30 A comparative example (planter A) of a lighting system for lighting up a plant bed, and two examples of lighting systems for lighting up the same plant bed (planters B and C) are described below. The main objectives that these lighting systems try to meet are to be effective for plant growth and enable pleasant viewing of plants and at the same time isolate the results of static versus dynamic set-up. In the present disclosure, a planter refers to a container used for growing and displaying plants, typically made of wood, plastic, and/or metal. Software simulations were conducted for the lighting systems of planters A to C to produce heat or heat maps to illustrate their efficiency in providing a desired level of PPFD. Physical testbeds were set up to gauge and compare the difference in performance of planters A to C. The desired results to achieve refer to the creation of a lighting system that is effective for plant growth, enables pleasant viewing of plants, and provides energy and cost savings. The lighting system of planter A is an example of a static set-up that did not produce the desired results for plant growth. The lighting system of planter B is a static set-up that is not ideal in terms of energy consumption but produced acceptable results for plant growth. The lighting system of planter C is a dynamic set-up (i.e. with moving parts) that produced the best results for plant growth and energy consumption.
- 35
- 40
- 45 The PPFD calculation and set-ups for planters A to C are described as follow with reference to Fig. 2 to Fig. 7D.
1. PPFD calculation
- 50 The desired PPFD was first determined for the plants to be grown for planters A to C. The PPFD values were converted into Lux. The power consumption in terms of Wattage was determined

from the Lux values. Correction or conversion factors to obtain Lux from the desired PPFD were used. For planters A to C, based on the plants to be grown, a PPFD value of more than $50 \mu\text{mol m}^{-2} \text{s}^{-1}$ was predetermined as desirable for plant growth.

- 5 A light fixture proposed for planter A to C was configured to have a neutral white light plant pre-formulated growth spectrum (3800K) with CRI > 90, R9 > 90 and UGR < 10, which includes coloured light for plant growth that are masked. Such light spectrum can be regarded as a balanced plant growth light spectrum, a neutral white light close to daylight. The light fixture was configured to have a plurality of light sources i.e. one circular lamp comprising the plurality of light
- 10 sources. The light fixture has a nominal power of about 17.5W. A software simulation prepared based on parameters inputted (e.g. parameters inputted at step 102 described earlier) was performed to simulate the lighting effect. Heat maps such as Fig. 5D and 5E were generated during the simulation to analyse whether the PPFD requirements for plant growth are met.

15 2. Area of Light Coverage

- The same light beam shape option was provided for planters A to C since the plant types, planting bed area and light fixture distances from the planting bed are kept constant. The light beam shape should have the least light spillage, least light loss, and the highest PPFD (or average PPFD)
- 20 required for the plants to be grown. The proposed light fixtures for planters A to C comprises at least one single 17.5W light fixture. One of such light fixture can project a circular light beam that provides more than or equal to PPFD of $50 \mu\text{mol m}^{-2} \text{s}^{-1}$ for a circular area within a 360 mm diameter. The light projected beyond the 360 mm diameter will provide lesser than $50 \mu\text{mol m}^{-2} \text{s}^{-1}$.
- 25 However, to fully utilize all of the light to prevent light spillage, the width of the planter used for containing the plants to be grown was stretched to about 550 mm. Hence, the planting area to be lighted was determined to be 550mm x 550mm, as shown in Fig. 3A. Fig. 3B shows a heat map generated via software simulation for one of the proposed light fixture. Lux values are shown in Fig. 3B. The light shone by the light fixture shines light with highest Lux at a center and the Lux decreases away from the center. Fig. 3C shows a heat map corresponding to the heat map of Fig.
- 30 3B containing PPFD values instead of Lux. A predetermined correction or conversion factor or formula was used to convert the PPFD to Lux or Lux to PPFD as required. The Lux can help to determine the required Wattage of the light source of the light fixture.

35 3. Height of Fixture

- The mounting height for planters A to C were pre-determined to achieve the desired PPFD of $50 \mu\text{mol m}^{-2} \text{s}^{-1}$ and the dimensions of the area of coverage. For all planters A to C, the light fixture was adjusted to have a height of 1m from the light source to the plants.

40 4. Testbed layout and dimensions

The testbed layouts and dimensions for planters A to C are described below.

- 45 Different lighting set-ups were proposed for planters A to C. The set-ups of Planter A and Planter C comprised one light fixture and Planter B comprised two light fixtures, double of Planters A and C. The light fixtures used were made the same so that there is no added advantage due to use of better lighting equipment. This was for fairer comparison.

- 50 The targeted areas of greenery or the plant beds for planters A to C are the same. Fig. 4A shows a top view of each of the plant beds 402. The plant bed 402 is rectangular with a width of about 550 mm and length of about 1400 mm. There are a plurality of pots or holders of plants placed in

the plant bed 402. Each pot or holder is given a reference numeral, which represents a zone. There are 4 zones in the plant bed 402. There are 3 rows of pots or holders of plants. The distance between every 2 pots or holders is about 175 mm along the width of the set up and the distance between every 2 pots or holders is about 200 mm along the length of the set up. There are 19 pots of 4 species of plants for each planter A, B or C. Zone 1 has 1 pot of a first plant, Chlorophytum, at the center of the plant bed 402. Zone 2 has 6 pots of a second plant, Krakau (lipsticks), surrounding the Zone 1 pot. Zone 3 has 6 pots of a third plant, Peperomia Variegated, placed to the side of the zone 2 pots away from the center of the plant bed 402. Zone 4 has 6 pots of a fourth plant, Ferns, placed at the boundaries of plant bed 402. Fig. 4B and 4C show the height of the plant bed 402, which is 400 mm. Fig. 4B shows a front view of a long side (length) of the plant bed 402 and Fig. 4C shows a side view of a short side (width) of the plant bed 402. Fig. 9 shows specific numbers in the form of X.Y given for every pot of plant in the plant bed 402, wherein X represents zone number and Y represents pot number.

5. Nominal Set-up

The lighting system of planter A had a nominal set-up 500. Fig. 5A shows a side view of a shorter side (width) of the set-up 500 and Fig. 5B shows a front view of a longer side (length) of the set-up 500. The set-up 500 has a stand comprising a plurality of legs 508, specifically, 4 legs adjacent to 4 corners of a rectangular plant bed 502. The plant bed 502 is the same as the plant bed 402 of Fig. 4A. The plurality of legs 508 are joined to a central support frame 506. A light fixture 504 is mounted at the center of the central support frame 506 so as to shine light at the center of the plant bed 502. The light fixture 504 comprises one or more light sources to project the light beam described with references to Fig. 3A to 3C. The light fixture 504 provides light with intensity strongest at a center and weaker further away from the center. In the side view of Fig. 5A, the center of the light source of the light fixture 504 is about 300 mm away from the legs 508. The width of the set-up 500 is about 600 mm. In the front view of Fig. 5B, the height of the light source to the top of the plants (or the PPFD measurement plane) is 1000 mm or 1 m. The wattage of the light fixture 504 is fixed at 17.5W. Fig. 5C shows that a top view of the plant bed 502. In Fig. 5C, a center 510 of the plant bed 502 where the light fixture 504 is located above is 275 mm away from the long sides of the plant bed 502 and the center 510 of the plant bed 502 is 700 mm away from the short sides of the plant bed 502. Through the help of a software simulation, it was worked out that the area coverage that can provide PPFD of $50 \mu\text{mol m}^{-2} \text{s}^{-1}$ was 0.101 m^2 . The light area coverage including light spill was 0.238 m^2 .

Clearly, the light coverage provided by a single light fixture of 17.5W was insufficient. Fig. 5D shows a heat map created by software simulation to show the Lux values of light shone on the plant bed 502 by the light fixture 504. Fig. 5E shows a heat map of the PPFD values of the light shone by the light fixture 504. In Fig. 5E, there are visible and expected plant areas that will have minimal or no growth i.e. zones 3 and 4 in Fig. 4A, which had PPFD value of $50 \mu\text{mol m}^{-2} \text{s}^{-1}$ or less.

To improve on the design of the lighting system of planter A, it is possible to change the light source of the set-up 500 to have lenses to provide wider beam so as to spread light and reach zones 3 and 4. However, there will be issues such as the following.

- a. There will be light spillage to the surroundings beyond the plant bed 502. More light spillage indicates lesser efficiency and more energy wastage. More light spillage will also cause the lighted plant bed 502 and in particular, its surroundings to be unsightly and/or glaring to people.
- b. Keeping the fixture wattage constant, the wider beam will provide lower light intensity and the preferred average PPFD of $50 \mu\text{mol m}^{-2} \text{s}^{-1}$ will not be achieved.

6. Solution to Planter A

One solution to improve planter A is to provide a linear array of more than one light fixtures. For instance, two of the light fixture 604 can be disposed above a plant bed 602. The plant bed 602 is the same as the plant bed 402 of Fig. 4A. However, having two light fixtures will require more than 17.5W i.e. $2 \times 17.5W = 35W$. Energy consumption and energy cost are doubled compared to the lighting system of planter A. The lighting system of planter B is an example of such solution.

With reference to Fig. 6A, the lighting system of planter B had a similar set-up 600 as the set-up 500 for planter A except that there was an additional light fixture. Fig. 6A shows a front view of a longer side (length) of the set-up 600. The set-up 600 has a stand comprising a plurality of legs 608, specifically, 4 legs adjacent to 4 corners of the rectangular plant bed 602. The plurality of legs 608 are joined to a central support frame 606. Two light fixtures 604a and 604b are mounted at the center of the central support frame 606. Each of the light fixtures 604a and 604b has the same hardware as the light fixture 504 of the lighting system of planter A. Each of the light fixtures 604a and 604b projects the light beam described with references to Fig. 3A to 3C. In the front view of Fig. 6A, the height of the light sources of the light fixtures 604a and 604b to the top of the plants (or the PPFD measurement plane) is 1000 mm or 1 m. Fig. 6B shows a top view of the plant bed 602. There are two spots 610 and 612 drawn in the plant bed 602 where the two light fixtures 604a and 604b are located above respectively. The two spots 610 and 612 are located 700 mm away from each other. They are symmetrical about an axis at the middle of the length of the plant bed 602. Each of the two spots is 350 mm away from the short sides of the plant bed 602 and 275 mm away from the long sides of the plant bed 602. Through the help of a software simulation, it was worked out that the area coverage that can provide PPFD of $50 \mu\text{mol m}^{-2} \text{s}^{-1}$ is 0.202 m^2 (2 times of planter A). The light area coverage including light spill was 0.475 m^2 (2 times of planter A).

Fig. 6C shows a heat map created by software simulation showing the Lux values of the light shone on the plant bed 602 by the two light fixtures 604a and 604b. Fig. 6D shows a heat map containing PPFD values of the light shone by the two light fixtures 604a and 604b. However, compared to planter A, the situation is much better and the lighting system of planter B is considered to be acceptable for plant growth. There are no areas with minimal or no growth. The lighting system of planter B can be further improved through the implementation of the lighting system of planter C.

7. Innovation

With reference to Fig. 7A and 7B, the lighting system of planter C had a similar set-up 700 as the set-up 500 for planter A except that the light fixture is configured to be movable. Fig. 7A shows a front view of a longer side (length) of the set-up 700 and Fig. 7B shows a side view of a shorter side (width) of the set-up 700. The set-up 700 has a stand comprising a plurality of legs 708, specifically, 4 legs adjacent to 4 corners of a rectangular plant bed 702. The plant bed 702 is the same as the plant bed 402 in Fig. 4A. The plurality of legs 708 are joined to a central support frame 706. A Strategic Dynamic Light Distribution (SDLD) mechanism (or actuator) 710 is provided. A light fixture 704 having the same hardware as the light fixture 504 of Fig. 5A is mounted to the SDLD mechanism 710. The light fixture 704 comprises one or more light sources to project the light beam described with references to Fig. 3A to 3C. The SDLD mechanism 710 is configured to move the light fixture 704 along the length of the central support frame 706 from a position A to a position B. For planter C, the SDLD mechanism 710 is configured to have a driver such as a motor to drive linear movements of the light fixture 704 and a rail for the light fixture 704 to move between positions A and B. With reference to the top view of the plant bed 602 in

Fig. 6B, which is the same as the plant bed 702, position A is at the position of the spot 610 in Fig. 6B and position B is at the position of the spot 612 in Fig. 6B. Position A is about 700 mm away from position B. Both positions A and B are about 350 mm away from the short sides of the plant bed 702 and about 275 mm away from the long sides of the plant bed 702.

5 The lighting system of planter C comprises a processor or controller, which can be provided with the SDLD mechanism 710, to configure movement parameters of the light fixture 704. The movement parameters include pre-determined length of movement of the light fixture 704, movement speed of the light fixture 704 and number of movement cycles of the light fixture 704.

10 A cycle refers to moving from any point in the movement path of the light fixture 704 back to the same point (e.g. position A back to position A or position B back to position B). Specifically, the movement parameters configured for the light fixture 704 of planter C were movement length of 700mm (distance between positions A and B) and movement speed of about 0.05 mm/s, which works out to be about 3 cycles in 12 hours. The total energy consumption in terms of wattage was about 22.5W i.e. 17.5W for the light fixture 704 and 5W for the operation of the SDLD mechanism 710. Through the help of a software simulation, it was worked out that the area coverage that can provide PPFD of 50 $\mu\text{mol m}^{-2} \text{s}^{-1}$ is 0.3525 m^2 (3.5 times of planter A and 1.75 times of planter B). The light area coverage including light spill was 0.623 m^2 (2.6 times of planter A and 1.31 times of planter B).

20 The results of the lighting system of planter C are beyond promising. Fig. 7C shows a heat map created by software simulation to show the Lux values of light shone on the plant bed 702 by the light fixture 704. Fig. 7D shows a heat map showing the PPFD values of the light shone by the light fixture 704. In Fig. 7D, there are some expected areas of minimal growth, in particular zone 4 (refer to Fig. 4A), due to insufficient photoperiod (duration of light shining). Although there are still areas with minimal growth, the light coverage for plant growth was still improved over the lighting systems of planters A and B. Furthermore, the power consumption was just 5W higher than that of the lighting system for planter A and a notable 12.5W lower than that of the lighting system for planter B. With a 12.5W lower power consumption, the coverage area of planter C is not compromised at all, maintaining the same minimum of 50 $\mu\text{mol m}^{-2} \text{s}^{-1}$ (50PPFD) coverage area as planter B. Incredibly, with just 5W more power consumption, the minimum 50PPFD coverage area is now increased by 348% (0.3525 m^2 /0.1012 m^2) when compared to planter A.

35 If required, the lighting system of planter C can be further improved to provide more light to zone 4. For instance, the lighting system can be configured to increase the photoperiod of shining light at zone 4, the distance of positions A and B can be made slightly longer for the light fixture 704 to shine more light at zone 4, and the light fixture 704 can be configured to oscillate or rotate to have light reach the far ends of zone 4. The cycling starting points can also be fine-tuned as well to improve the lighting for zone 4.

40 Table 1 below summarizes the results obtained from software simulation comparing planter C to planters A and B.

Table 1:

Coverage for PPFD value of 50 at 1m distance	Planter A: Single Static	Planter B: Double Static	Planter C: Single Dynamic
Measured fixture power consumption (W)	17.5	35	17.5

Mechanism (Actuator) (W)	0	0	5
Total Wattage (W)	17.5	35	22.5
Diameter (mm)	359	359 x 1059	359 x 1059
Coverage area (m ²)	0.1012	0.3525	0.3525
**Wattage required to cover the same 0.3525m ² (W)	60.9	35.0	22.5
Overall Wattage Savings from Changing to Single Dynamic	63%	36%	
**Wattage per its coverage area (W/m ²)	172.89	99.28	63.83
Wattage Ratio Comparison with lighting system of Planter C as Base	2.71	1.56	1.00

** The wattage required to cover said area is an empirical result of the light fixture of planter A multiplied to cover the larger area of 0.3525m². This result is calculated only for comparison sake. In reality, the lighting system of planter A is unable to cover zones with minimal or no plant growth, and planter B or C has to replace planter A for better light coverage.

5

The physical experiments conducted for planters A to C are described in detail as follow.

1. There are 3 planters A to C with 19 pots of plants in each of the plant beds 502, 602 and 702 shown in Fig. 5B, Fig. 6A and Fig. 7A respectively.

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2. In the experiments, each pot and planter have the following constant factors:

- Same type of growing medium for the same species.
- Watering of 200ml/pot for 2 times/week for each pot.
- Light from the surrounding is almost zero. The surrounding is a dark room with black painted walls that have no light reflectance.
- An air ventilator has a timer set for alternating 1 hour ON and 1 hour OFF for 24 hours daily and 7 days a week.
- Fertilization of the plants is performed with diluted seasol, at a ratio of 1:40, and evenly sprayed on all plants once every two weeks. Seasol is made from liquid seaweed extract from a specific blend of kelp species including King Island Bull Kelp.

20

3. The lighting conditions of the surroundings of the planters A to C are as follow.

- There is almost zero Lux at the testing areas of planters A to C. Hence, the source of light will be solely from the light fixtures 504, 604a and 604b, and 704 provided for the planters A to C as described with reference to Fig. 5A to Fig. 7D. Measurement of the surrounding PPFD is 0.003 $\mu\text{mol m}^{-2} \text{s}^{-1}$.
- All 3 planters A to C are located in the same dark room. There are matte black metal partitions between the planters A to C. Hence, there is no light sharing between the three planters A to C and no light reflection from the matte black partitions to the planters A to C.

30

4. The plants for each plant bed 502, 602 and 702 of the planters A to C respectively are arranged as follow.

- The plants in the planter area are divided into Zone 1, Zone 2, Zone 3 and Zone 4 respectively.
- Zone 1 consists of 1 pot of plant at the center of the planter.
- Zone 2 consists of 6 pots of plants, 3 each on the left and right at the outer layer of Zone 1.
- Zone 3 consists of 6 pots of plants, 3 each on the left and right at the outer layer of Zone 2.
- Zone 4 consists of 6 pots of plants, 3 each on the left and right at the outer layer of Zone 3.

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5. The physical experiments were meant to record the growth of the plants in each planter's zones.
The sample size for measurement of each planter's zones is as follows:
- a. Zone 1: 1 (pre-identified) pot.
 - 5 b. Zones 2, 3 and 4: 2 (pre-identified) pots for each of these zones.
6. The following were measured and tabulated for comparison:
- a. Average height (mm), from the pot soil level, using 1 reference point per pot.
 - b. Average diameter (mm), using 1 reference point per pot.
 - 10 c. Average stem elongation, distance (mm) between the leaf nodes.
 - d. Leaf lushness and density:
 - i. Number of leaves in images captured.
 - ii. Average length (mm) of leaves.
 - iii. Average width (mm) of leaves.
 - 15 e. Appearance
Photo-taking of each planter at pre-set locations; one from the front view and one from the top view.
Features to look out for when comparing the photographs taken:
 - i. Whether the leaf colour turns pale green, yellow or white.
 - 20 ii. Whether the leaves are dropping, etiolated or browning or having any sign of anomaly.
 - iii. Whether the stem becomes "leggy".
 7. Photographs for creating a time lapse video were captured for all three planters A to C.
 8. Watering, fertilization, data measurement, and photo-taking were scheduled for all three planters A to C.
 - 25 9. The measured data were tabulated.
 10. Photographs of the planters A to C were taken every day.
 11. The point PPFD value received by each pot under the single light fixture 504 of planter A and double light fixtures 604a and 604b of planter B were recorded. With regard to PPFD Measurement, the starting PPFD at the location of each pot is measured with the single light fixture 504 and double light fixtures 604a and 604b switched on before the start of the experiment. The measurement was taken with a meter facing upwards vertically i.e. not cosine corrected. The same measurement was repeated for the single light fixture 504 and the double light fixtures 604a and 604b. Table 2 below shows the starting PPFD values that were measured. Refer to Fig. 9 for zone/pot number.
 - 30
 - 35

Table 2:

Zone/Pot Number	Single Fixture (Planter A)	Double Fixture (Planter B)
Zone 1	592	15
2.1	32	15
2.2	29	110
2.3	30	24
2.4	29	15
2.5	39	52
2.6	33	14
Zone 2 Average	32	38

3.1	10	20
3.2	6	344
3.3	8	96
3.4	10	66
3.5	7	448
3.6	12	32
Zone 3 Average	9	168
4.1	1	16
4.2	0.6	16
4.3	1	26
4.4	1	29
4.5	0.5	23
4.6	1	21
Zone 4 Average	1	22

12. The single light fixture 504 of planter A and the double light fixtures 604a and 604b of planter B were switched on for 12 hours a day and off for the other 12 hours. The single dynamic light fixture 704 of planter C was switched on for 12 hours a day and off for the other 12 hours. While the single dynamic light fixture 704 was switched on for the first day, it moved from a midway point between position A and position B to position A, then to position B, and back to the midway point in 4 hours. This is deemed as the first cycle. Thereafter, the single dynamic light fixture 704 moved in a second cycle for another 4 hours. In the second cycle, it moved from the midway point to position B, then to position A, and back to the midway point. Subsequently, the single dynamic light fixture 704 moved in a third cycle for yet another 4 hours. In the third cycle, it moved from the midway point between position A and position B to position A, then to position B, and back to the midway point. The distance moved by the single dynamic light fixture 704 for each cycle is 700mm.
- 15 The findings of the physical experiments are as follow.

Day 1 vs Day 57 Measurements and Observations are shown in table 3 below. Reference is made to the zone/pot numbers in Fig. 9. In table 3, the specific pot number of each planter A, B or C is denoted by WX.Y, where W refers to Planter W, X refers to Zone X and Y refers to pot number Y. For instance, A4.1 refers to planter A, zone 4, and pot number 1.

Table 3:

	Planter A: Single Static	Planter B: Double Static	Planter C: Single Dynamic
Day 1			
Ave. Measurement	A	B	C
Plant Height (mm)	157.50	158.75	155.00
Plant Diameter (mm)	178.75	156.25	177.50

Internode Dist. (mm)	18.33		21.67		18.33	
Length(mm) of Leaves	130.00		130.00		132.50	
Width(mm) of Leaves	33.75		35.00		36.25	
Day 57						
Observations on Day 57	A4.1~A4.6 are dead. A3.5 & A3.6 are dying, both of them having only one stem left. Only plants below the light source are surviving. However, the rest of the plants are browning and withering. This is due to visible lack of light coverage and the PPFD measurement.		B4.1~4.6 are growing with highest positive phototropism. B2.1~2.6, and B4.1~4.6 plants are bending towards the light fixtures. B4.1 and B4.2 have excessive etiolation, long weak stems, longer internodes, and are unable to support themselves. The plants where the double light fixtures spotlights over are experiencing excessive phototropism, bending themselves towards the light source, which gives the planter an uneven height across a horizontal plane with long weak stems that are unable to support themselves.		C4.2 is starting to wither, due to insufficient photoperiod as predicted. C1 leaves are wider, taller & lusher than A1 & B1. C4.4 is experiencing a slight degree of positive phototropism and bending towards the light source. Although there is slight uneven growth and one pot of plant is starting to wither, overall, Planter C shows the most uniform growth across all different zones.	
	Ave. Measurement		B		C	
Plant Height (mm) / Growth %	125.00	-21%	186.25	+17%	173.75	+12%
Plant Diameter (mm) / Growth %	138.75	-22%	185.00	+18%	178.75	+1%
Note: Plant height and diameter represent the plant growth, positive value for growth and negative value for deterioration of growth.						
No. of unhealthy (dying or	9		0		1	

browning) pots			
No. of flowers bloomed	1	0	4

More details on the findings of day 1 and day 57 are provided below. Some measurements were made using a goniometer.

- 5 1. Plant Height
Measurements for day 1 and day 57 are provided in Fig. 10A.
 - Planters A and B experienced extreme and uneven growth and non-growth.
 - Plants in zone 3 of planter A were dying and the plants in zone 4 were dead.
 - Plants in zone 4 of planter B reached for the light sources with accelerated growth, leading to
- 10 extreme and uneven growth.
 - Planter C showed most uniform growth and even outlook across all zones. The plants grew naturally over time.
2. Plant Diameter:
Measurements for day 1 and day 57 are provided in Fig. 10B.
- 15 - Planter A: Plant growth spiked under the light source, and plants not under the light were dying or dead.
 - Planter B: Plant growth spiked under the light source with moderate growth observed for plants not under the light. Excessive phototropism was observed.
 - Planter C: No significant plant growth spikes. Natural growth was observed.
- 20 3. Internode Distance
Measurements for day 1 and day 57 are provided in Fig. 10C.
 - Planters A and B experienced elongated internode distance due to uneven light coverage. For planter B, the plants showed phototropism and had more leggy outlook with weak long stems.
 - Planter C maintained the healthy normal internode distance as the plants did not have to stretch
- 25 and reach out to the light source.
4. Leaves Length
Measurements for day 1 and day 57 are provided in Fig. 10D.
 - Plants in zone 4 of planter A were dead, indicating least growth in leaves length.
 - Planters B and C did not have significant changes in the length of their leaves.
- 30 5. Leaves Width
Measurements for day 1 and day 57 are provided in Fig. 10E.
 - Plants in zone 3 of planter A were dying and the plants in zone 4 were dead.
 - Pot 1 of zone 1 of planter C had more count of wider leaves than pot 1 of zone 1 of planters A and B.
- 35 6. Comparison of Photographs by Zones
Zone 1:
 - Planter A: Showed negative phototropism. The leaves tried to shy away from the hot spot.
 - Planter B: The leaves were trying to reach the light sources.
 - Planter C: Best visible growth. Visibly lush and denser, by the count of the number of leaves
- 40 and the measurement of their widths.
Zone 2:
 - All three planters A to C were doing generally well.
 - Planter A and C flowered. No flowering in Planter B.
- Zone 3:
 - A3.4 to A3.6 (See Fig. 9) of planter A were not doing well.
 - Planter B had accelerated growth for plants where the lights were directly above, leading to uneven growth.

- The plants in planter C were thriving naturally.
- Zone 4:
 - All plants in zone 4 of planter A were dead. Single static light fixture provides insufficient light coverage.
- 5 - The plants under the light sources in planter B were overgrown and were reaching for the light sources.
- C4.2 (See Fig. 9) of planter C was browning due to insufficient photoperiod.
- C4.4 to C4.6 (See Fig. 9) were thriving due to sufficient photoperiod. The start points of cycling can be fine-tuned to provide better coverage for C4.1 to C4.3 as well. The default start point of
- 10 each cycle is currently the midway point between position A and position B shown in Fig. 7A. Such start point can be adjusted. The end point can be adjusted as well to optimise growth for all the plants.
- 7. Conclusion (from the Experimental Findings)
 - a. The created balanced plant growth light spectrum i.e. neutral white light plant growth spectrum (3800K), which includes coloured light for plant growth that are masked works well to provide
 - 15 plant growth. The wattage is 17.5W per light fixture.
 - b. From the results of planter A, it is clear that a single light fixture provides insufficient light coverage.
 - c. A solution of adding more light sources works and grew all the plants for planter B. However,
 - 20 excessive phototropism occurred and there were elongated stem growth (longer internode distance). Hence, more maintenance (plant trimming) is required. Overall, planter B has less desirable outlook and will cost more in all aspects, especially in energy and maintenance.
 - d. The innovative dynamic lighting system of planter C had proven its effectiveness, demonstrating healthy plant growth at a correct pace (and lesser maintenance is required),
 - 25 uniform plant growth (best aesthetic outlook) and more flowering occurred compared to planters A and B. Overall, there was good plant health, plant growth and plant appearance.
 - e. Planter C showed a positive effect on plants when light intensity varies throughout the day and when the plants were lighted from different angles, just like natural sunlight.
- 30 Examples of a light fixture of the present disclosure (e.g. 504 in Fig. 5B, 604a and 604b in Fig. 6A, and 704 in Fig. 7A) may be configured according to four examples of light fixtures 1302, 1304, 1306 and 1308 shown in Fig. 13A to 13D, or in a similar manner. Fig. 13A to 13D show views of the light fixtures 1302, 1304, 1306 and 1308 when looking in a direction of a plurality of light
- 35 sources mounted to the light fixtures. Specifically, Fig. 13A and 13B show light fixtures 1302 and 1304 with rectangular shape. In other examples, square or triangle shape may also be possible. Fig. 13C and 13D show light fixtures 1306 and 1308 with circular shape. A plurality of light sources are mounted to each light fixture 1302, 1304, 1306 and 1308 of Fig. 13A to 13D respectively in an organised manner.
- 40 In addition to the use of secondary optics (lenses, reflectors, and/or diffusers) for light distribution, the light output may be tilted or angled by tilting or angling each light source. This can be done, for instance, for a vertical green wall where light fixtures are typically mounted at a ceiling and light has to be angled and distributed across the height of the green wall. Greater intensity of light
- 45 can be provided to reach areas at a greater distance away from the light fixtures. Where possible, light overlapping can be done to increase PPFD intensity and coverage for specific areas requiring higher PPFD, instead of upsizing the wattage of the light fixture to achieve higher intensity, which increases power consumption.
- 50 In Fig. 13A to 13D, each small circle represents a light source, for instance, an LED, a light bulb or lamp. W represents white light source, R represents red light source (provides Red and/or far red for plant growth), B represents blue light source, W/R represents a customised blend of white

and red light and W/B represents a customised blend of white and blue light. The correct ratio of white, red and blue light sources will provide sufficient PPFD for plant growth as well as a pleasant light output for viewing. Each light source W, R, B, W/R, or W/B shown in Fig. 13A to 13D may be individually tilted or angled to focus light on a specific spot in a target area of greenery. The light sources may also be tilted or angled as a group. For example, there may be 3 groups of 9 LED light sources in a light fixture and each group is tiltable in different directions. The light sources can be individually tilted to achieve better light distribution and colour blending. The light sources R, B, W/R, and/or W/B can have different arrangements to achieve even light distribution. For example, R, B, W/R, and/or W/B may be evenly distributed among W so that colour blending will be even. The number of coloured light sources R, B, W/R, and/or W/B can determine the colour temperature. A key aspect of all the light fixtures is that the white light output should be sufficient to mask the coloured lights required for plant growth and to produce light to be shone on plants for pleasant viewing of the plants. The light fixture 504 in Fig. 5B, 604a or 604b in Fig. 6A, or 704 in Fig. 7A may be configured to have the configuration of Fig. 13C or Fig. 13D.

The light fixture of the lighting system of planter C can be adjusted to improve energy usage to offset the 5W additional power to be used for the dynamic mechanism. For instance, by adjusting and optimising movement path, movement speed, cycling, light intensity, etc. With reference to the examples of light fixtures of Fig. 13A to 13C, angling or tilting light of individual light sources to focus light at different areas of a targeted area of greenery can also help to optimise and result in improved energy usage.

Furthermore, in actual indoor greenery applications, the light fixtures are expected to be installed much higher (i.e. close to or higher than 800 mm). Hence, it is more likely to use 70W or 105W per light fixture for further distances between the light sources and the plants, instead of 17.5W due to the inverse square law of light. This will make the additional 5W for operating the dynamic mechanism of the example of planter C seem trivial to the overall wattage of the lighting system. In most cases, it is expected that the number of dynamic mechanisms to be used would be lower than the number of light fixtures. In some cases, the same dynamic mechanism can be used to provide linear movement across all designed light fixtures. In such cases, as the 5W to be used by the dynamic mechanism can be kept at a constant, cost savings will be higher for higher wattage light fixtures. For example, 5W of 17.5W is a 28.6% increase in power usage for a lighting system comprising a single 17.5W dynamic light fixture. 5W of 105W is just a 4.8% increase in power usage for a lighting system with 105W dynamic light fixtures that can provide 6 times the light intensity of the single 17.5W light fixture.

Based on today's standards, the positive economic and environmental impact of using the lighting system of planter C after optimization is illustrated in Table 4 as follows. The currency is Singapore Dollars.

Table 4:

Today's standards:		
\$/kWh	Estimated CO2 Emission / kWh	Estimated Number of trees to absorb 1kg of carbon emissions
\$ 0.30	0.408 kg	0.0493
Expected Savings from Use of Lighting System of Planter C:		

For Planter Area of 10 times the Testbed Size (i.e. 10 times the size of the plant bed 402 of Fig. 4A)	Planter A: Single Static	Planter B: Double Static	Planter C: Single Dynamic
Fixture Wattage	17.5 W	35 W	22.5 W
Savings from lighting optimization and from use of less of the 5W dynamic mechanisms for large plant bed size	-	-	17.5 W (Lowered by about 5W after optimization and use of lesser dynamic mechanisms)
Quantity	10 pcs	10 Pcs	10 pcs
Total Wattage	175 W	350 W	175 W
By changing to Single Dynamic Light fixture, one can save:	0%	About 50.00%	
Operating hours / day	12 hrs	12 hrs	12 hrs
kWh / year	767 kWh	1,533 kWh	767 kWh
\$ / year	\$ 229.95	\$ 459.90	\$ 229.95
CO ₂ emission / year	312.73 kg	625.46 kg	312.73 kg
Number of rainforest tree to absorb the CO ₂ emission	16 trees	31 trees	16 trees
By changing to Single Dynamic Light fixture, one can save:	-	312.73 kg of CO ₂ emissions, and 15 trees	

5 The innovative solution of planter C demonstrates the ability to significantly reduce initial equipment costs (encompassing savings in installation and maintenance costs as well as recurring costs), resulting in concurrent decrease in energy costs while delivering better outcomes in achieving a denser, even, and lush plant growth. This achievement is made possible through precise calculations of the coverage and speed control coupled with the correct PPFD value distributed across the targeted area. Importantly, there are no trade-offs, only gains. The approach of planter C mimics natural sun-like movement, creating more captivating and organic illumination of the greenery, replete with dimension, texture and depth.

10 Beyond the commercial economic benefits, the lighting system of planter C moves away from the constraints of a static "floodlight" arrangement, which lacks in control and intensity. Such static arrangement can provide even coverage but only at close range, for instance, lesser than 16cm. The approach of planter C departs static spotty illumination like the lighting system of planter B, which may offer stronger but uneven light coverage. Lighting systems like those of planter B demand a higher number of fixtures and uses more power than the lighting system of planter C. The reduction in equipment in the case of planter C not only yields cost savings but also enhances the overall green design and provides more vantage points for appreciating, enjoying and engaging with the greenery. It underscores the symbiotic coexistence between human and nature, justifying its integration into our surroundings. These advantages are unattainable with traditional

plant grow lights. Traditional plant grow lights have limited colour rendering capabilities for achieving pleasant viewing. As a result, the innovation of planter C opens up opportunities for more creative biophilic design elements indoors, enabling the establishment of sustainable, liveable garden anywhere void of sunlight with planters, trees and living walls.

5

In addition to the compelling cost and energy-saving incentives for increased adoption rates, the innovative solution of planter C can provide numerous advantages to both plants and the space, and also benefit the community and environment. These advantages for plants and space are stated below.

10

Benefits for Plants:

1. Angled Light and Even Distribution: Angled light achieved from moving the light fixture helps to distribute light more evenly across the plant canopy. Angled light mimics natural conditions, promoting the growth throughout the plant, optimizes photosynthesis process, stimulating natural responses. Avoids plant growing towards a light source, preventing excessive elongation towards light direction (Phototropism). In addition to achieving angled light from moving the light fixture, with reference to Fig. 13A to 13D, better light angling can also be achieved by individually tilting or angling light sources to focus light at areas of the plant bed more efficiently.

15

2. PPFD Uniformity: This promotes uniform and robust growth across entire plant canopy. It also minimizes shadow areas and reduces the need for plants to compete for light. Plant etiolation can be prevented.

20

3. Natural Growth: The dynamic approach encourages plants to grow naturally in all directions, not just towards static light sources, resulting in balanced and healthier development and appearance. In nature, plants receive light from various angles throughout the day as the sun moves across the sky. This prevents self-shading, where upper leaves block light from reaching lower leaves. Light movement and day-night cycles regulate plant circadian rhythms, which influence various physiological processes, including growth, nutrient uptake, and defence mechanisms.

25

4. Eliminates Static Hot Spots and Dark Spots: Prevents the occurrence of uneven growth due to areas of excessive or insufficient light.

30

5. Prevents Light Burn and Photoinhibition: Angled and dynamic (moving) light protect plants from the damaging effects of excessive light exposure.

6. Deep Light Penetration: Ensures light reaches deeper and different parts of the plants, enhancing growth at all levels.

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7. Minimized Light Blockage: Prevents one plant from obstructing light to surrounding neighbouring plants, ensuring equitable access to light.

8. Enhanced Nutrient Absorption: Balanced and uniform growth, facilitated by angled light from light movement, allows plants to absorb nutrients more effectively. When all parts of the plant receive sufficient light, they can support increased nutrient absorption, utilization and productivity.

40

The health and vitality of plants are intrinsically linked to their ability to provide the essential environmental services such as air purification through photosynthesis, temperature regulation through transpiration, noise reduction, stress relief, improve mental well-being and provide food security. When plants are not healthy and robust, their capacity to fulfil these critical roles in our ecosystems is compromised.

45

Benefits for the Space:

1. Reduction in Equipment and Clutter: With high efficacy, fewer fixtures are needed, offering unobstructed views of greenery. This efficient approach contributes to cleaner, more open spaces that enhance the visual appeal of the environment. For example, only one fixture for planter C compared to two fixtures in the case of planter B.

50

2. Diverse Visual Light Environment: Offers versatile lighting environment with the ability to create different visual atmospheres, at the same time promote healthy plant growth.
 3. Multi-Purpose Equipment That Saves Energy and May be Used for Entertainment: A single set of equipment caters to plant growth, provides high quality illumination for human enjoyment of the greenery (with CRI>90, R9>90 growth spectrums), and if required, can offer a "horti-tainment" aspect where the movable light fixtures are used to create light shows, enhancing the overall engagement, aesthetics and appeal of the space.
 4. Green Mark Awards: The proposed innovative solution supports green and energy-efficient design initiatives, making it an ideal choice for projects seeking environmental certifications or green awards. By prioritizing energy conservation and sustainability, it contributes to improving overall quality of life in the spaces where it is installed.
 5. Facilitates Successful Biophilic Design Indoors: Promoting the creation of sustainable nature-inspired interior / sheltered spaces.
 6. Reputation and Brand Enhancement: Developers and organizations that prioritize sustainability tend to build stronger and more positive reputations that attract customers, investors and talent, translating to a competitive advantage, meeting their long-term sustainability goals.
 7. An Asset: Long term value creation.
 8. Unlocks Potential: The proposed innovative solution enables the utilization of virtually any space, whether devoid of sunlight or only a minimal amount, to cultivate plants and trees and create a delightful environment with nature or provide food security. Even the dimmest of basements or underground cities can be transformed into vibrant, thriving green spaces, benefiting everyone.
- Benefits for the Community and Environment:
1. Improved air quality: Healthy growing plants contribute to cleaner indoor air, creating healthier indoor environments for occupants.
 2. Psychological and Emotional Well-being: The integration of natural elements into human spaces has profound psychological and emotional benefits. Studies have shown that exposure to greenery reduces stress, enhances mood, and increases cognitive function, making spaces with indoor plants more conducive to productivity and relaxation.
 3. Access to Green Spaces: Enhances opportunities for social interaction, connection with nature, improving the quality of life.
 4. Contribution to global sustainability goals: Support initiatives related to climate action, biodiversity conservation and the reduction of carbon emissions.
 5. Food Security: In addition to supporting ornamental plants, the system can also be used to grow edible crops in urban environments. This can play a role in addressing food security issues by providing a reliable source of fresh, locally-grown produce.
 6. Plant Growth anywhere: Enables greenery in spaces without natural light, such as basements. This opens up new possibilities for incorporating greenery into a wider range of indoor spaces.
 7. Economic Opportunities: Promotes green industries and job creation.
 8. Community engagement and social cohesion. Spaces with indoor or sheltered greenery may attract people to gather, fostering a sense of belonging and collaboration with social interaction and involvement in sustainable practices.
 9. Drives productivity and innovation. Good plant growth is an objective of the proposed innovative solution. Being surrounded by healthy growing plants may drive human productivity and creativity. For example, when employees work in an environment that prioritizes sustainability with both plant growth and pleasant plant viewing and better air quality, they are more focused, energized and efficient and have lower stress levels and increased mental clarity.
 10. Resilience to social and climate disruptions. The proposed innovative solution can be implemented indoors to reuse unutilized spaces such as basements, offices and common areas

to reduce heat and create spaces for gathering, healing and growing food, to combat climate change and supply chain disruptions and contribute to healthier, more sustainable communities.

5 The sum of all of the above advantages, culminates to a transformative green technology; an imperative response to the complex challenges arising from climate change, social and rapid urbanization issues. This transformative green technology has the potential to turn what was once an unforgiving concrete jungle (i.e. city buildings devoid of plants) into a sustainable, harmonious liveable city embraced by nature, aligning with global sustainability goals. The particular problems that examples of the present disclosure seek to solve include the following.

10 Examples of light fixtures of the proposed lighting system are described as follow. “+/- A” in Fig. 15A to 15C and Fig. 16A to 16E refers to light beam angle range i.e. 1406 in Fig. 14A.

15 Fig. 15A shows a side view of a first example of a light fixture 1500a with tiltable features that can be used for the proposed lighting system of the present disclosure. The light fixture 1500a is mounted to a top mounting bracket 1502a. The light fixture 1500a is not configured to pivot about the bracket 1502a. The light fixture 1500a comprises one light source or in another example, a group of light sources, for shining or projecting light. The light source or group of light sources is configured to be tilted about a pivot 1504a and fixed at a particular angle. Specifically, “+ / - A” in
20 the figure indicates the angle range in which the light source or group of light source can be tilted so that its central optical axis focusing light at one angle is angled to focus the light beam at another angle in another direction. If the light fixture 1500a is horizontally disposed, it will provide top-down light projection suitable for horizontally disposed green area. However, if it is angled, it can be used for a vertical green wall or column (pillar).

25 Fig. 15B shows a side view of a second example of a light fixture 1500b with tiltable features that can be used for the proposed lighting system of the present disclosure. The light fixture 1500b is mounted to a top mounting bracket 1502b. The light fixture 1500b is not configured to pivot about the bracket 1502b. The light fixture 1500b comprises two light sources or in another example, two
30 groups of light sources, for shining or projecting light. One of the two light sources or one of the two groups of light sources is configured to be tilted about a pivot 1504b1 and fixed at a particular angle. The other one of the two light sources or the other one of the two groups of light sources is configured to be tilted about a pivot 1504b2 and fixed at a particular angle. Specifically, “+ / - A”
35 in the figure indicates the angle range in which each light source or each group of light source can be tilted so that its central optical axis focusing light at one angle is angled to focus the light beam at another angle in another direction. In the present example, the two light sources or the two groups of light sources are configured such that they are tiltable in opposite directions from each other. Their central optical axes will not cross in the present example but can be made to cross (and have their light paths overlap more) in other examples. If the two light sources or the
40 two groups of light sources are not angled, the light fixture 1500b will provide top-down light projection suitable for horizontally disposed green area. However, if they are angled, the light fixture 1500b can be used for a vertical green wall or column (pillar).

45 Fig. 15C shows a side view of a third example of a light fixture 1500c with tiltable features that can be used for the proposed lighting system of the present disclosure. The light fixture 1500c is pivotably mounted relative to a top mounting bracket 1502c. The light fixture 1500c is configured to pivotable about a pivot 1504c1 connecting the light fixture 1500c to the bracket 1502c. The light fixture 1500c comprises two light sources, or in another example, two groups of light sources, for shining or projecting light. One of the two light sources or one of the two groups of light sources
50 is configured to be tilted about a pivot 1504c2 and fixed at a particular angle. The other one of the two light sources or the other one of the two groups of light sources is configured to be tilted about

- a pivot 1504c3 and fixed at a particular angle. Specifically, "+ / - A" in the figure indicates the angle range in which the light fixture 1500c, each light source or each group of light source can be tilted so that its central optical axis focusing light at one angle is angled to focus the light beam at another angle in another direction. In the present example, the two light sources or the two groups of light sources are configured such that they are tiltable in opposite directions from each other. Their central optical axes will not cross in the present example but can be made to cross in other examples. As the light fixture 1500c is pivotable about the bracket 1502c, when in use, the light fixture 1500c can be tilted and fixed at an angle within a much wider angle range of, for instance, about 270 degrees (as shown in Fig. 15C) compared to the examples of Fig. 15A and Fig. 15B.
- If the light fixture 1500c, the two light sources or the two groups of light sources are not angled, the light fixture 1500c will provide top-down light projection suitable for horizontally disposed green area. However, if they are angled, the light fixture 1500c can be used for a vertical green wall or column (pillar). As there is greater range of angles covered by the light fixture 1500c compared to light fixtures 1500a and 1500b, the light fixture 1500c is preferably used for multi-layered gardens, wherein ground covers, shrubs, small trees, and/or big trees are all in one planting space.
- Fig. 16A shows a side view of an example of a linear motion light fixture 1600a with tiltable features that can be used for the proposed lighting system of the present disclosure. The light fixture 1600a (Plant Grow-light provider) can have the design and functions of the light fixtures of 1500a, 1500b or 1500c of Fig. 15A, 15B or 15C respectively or the design and functions of the light fixtures of 1600b, 1600c, 1600d or 1600e of Fig. 16B, 16C, 16D or 16E respectively. In the example of Fig. 16A, specifically, the light fixture 1600a is pivotably mounted to a top mounting bracket 1602a and is pivotable about a pivot 1604a. When in use, the light fixture 1600a can be tilted and set at an angle within an angle range like the light fixture 1500c of Fig. 15C, 1600b of Fig. 16B or 1600e of Fig. 16E. The bracket 1602a is slidably or moveably mounted to a guide rail 1608a or to rollers (not shown) that are moveable in the guide rail 1608a. The guide rail 1608a may have a pair of rails in some examples. An actuator 1606a, for instance, a motor is configured to, under user control, move the bracket 1602a, which in turn moves the light fixture 1600a linearly along the length of guide rail 1608a. The path of the guide rail 1608a may be curved if it is required for the light fixture 1600a to move in a curved or circular path.
- Fig. 16B shows a side view of a first example of an oscillating motion light fixture 1600b, which is pivotably mounted to a top mounting bracket 1602b and is pivotable about a pivot 1604b. An actuator 1606b such as a motor is configured to, under user control, oscillate the light fixture 1600b about the pivot 1604b. The direction of light focus of the light fixture 1600b can be adjusted to oscillate within an angle range of +/- A and set at a particular angle.
- Fig. 16C shows a side view of a second example of an oscillating motion light fixture 1600c, which is mounted to a top mounting bracket 1602c and not configured to pivot about the bracket 1602c. The light fixture 1600c comprises a light source or in another example, a group of light source, for shining or projecting light. The light source or the group of light sources is configured to be tilted about a pivot 1604c. An actuator 1606c such as a motor is configured to, under user control, oscillate the light source or the group of light sources in the light fixture 1600c about the pivot 1604c. The direction of light focus of the light fixture 1600c can be adjusted to oscillate within an angle range of +/- A and set at a particular angle.
- Fig. 16D shows a side view of a third example of an oscillating motion light fixture 1600d, which is mounted to a top mounting bracket 1602d and not configured to pivot about the bracket 1602d. The light fixture 1600d comprises two light sources or in another example, two groups of light

sources, for shining or projecting light. One of the two light sources or one of the two groups of light sources is configured to be tiltable about a pivot 1604d1. The other one of the two light sources or the other one of the two groups of light sources is configured to be tiltable about a pivot 1604d2. An actuator 1606d such as a motor (or more motors) is configured to, under user control, pivot each of the two light sources and/or each of the group of two light sources about their respective pivots 1604d1 and 1604d2 and set them at an angle within an angle range of $\pm A$. Specifically, " $\pm A$ " in the figure indicates the angle range in which each light source or each group of light source can be tilted so that its central optical axis focusing light at one angle is angled to focus the light beam at another angle in another direction. In the present example, the two light sources or the two groups of light sources are configured such that they are tiltable in opposite directions from each other. Their central optical axes will not cross in the present example but can be made to cross in other examples.

Fig. 16E shows a side view of a fourth example of an oscillating motion light fixture 1600e, which is pivotably mounted to a top mounting bracket 1602d and is pivotable about a pivot 1604e1. A first actuator 1606e1 such as a motor is configured to, under user control, oscillate the light fixture 1600e about the pivot 1604e1. The direction of light focus of the light fixture 1600e can be adjusted to oscillate within an angle range of $\pm A$ and set at a particular angle. The light fixture 1600e comprises two light sources or in another example, two groups of light sources, for shining or projecting light. One of the two light sources or one of the two groups of light sources is configured to be tiltable about a pivot 1604e2. The other one of the two light sources or the other one of the two groups of light sources is configured to be tiltable about a pivot 1604e2. A second actuator 1606e2 such as a motor (or more motors) is configured to, under user control, pivot each of the two light sources and/or each of the group of two light sources about their respective pivots 1604e2 and 1604e3 and set them at an angle within an angle range of $\pm A$. Specifically, " $\pm A$ " in the figure indicates the angle range in which each light source or each group of light source can be tilted so that its central optical axis focusing light at one angle is angled to focus the light beam at another angle in another direction. In the present example, the two light sources or the two groups of light sources are configured such that they are tiltable in opposite directions from each other. Their central optical axes will not cross in the present example but can be made to cross in other examples.

The light fixture 1600c of Fig. 16C is essentially the dynamic (movement adjustable) version of the light fixture 1500a of Fig. 15A. The light fixture 1600d of Fig. 16D is essentially the dynamic (movement adjustable) version of the light fixture 1500b of Fig. 15B. The light fixture 1600e of Fig. 16E is essentially the dynamic (movement adjustable) version of the light fixture 1500c of Fig. 15C.

Fig. 16F shows a side view of a first example of a rotating motion light assembly 1600f. The light assembly 1600f has a base plate 1614f for installing to a surface, which can be ground, a wall surface, or a raised surface. When installed on the ground, the light assembly 1600f would have a bollard or pole design. A central shaft 1612f is connected to the base plate 1614f. The central shaft 1612f comprises two portions, a first portion 1612f1 configured to rotate and a second portion 1612f2 that is mounted to the base plate 1614f and configured to be stationary. There is a middle section 1616f between the central shaft 1612f where the first portion 1612f1 is movably coupled to the second portion 1612f2. Two (plant grow-light) light fixtures 1600f1 and 1600f2 branch out from the first portion 1612f1. They extend out orthogonally relative to a longitudinal axis 1618f of the first portion 1612f1 in opposite directions from each other. The light fixtures 1600f1 and 1600f2 are pivotably mounted to two brackets 1602f1 and 1602f2 respectively and are configured to be pivotable about two pivots 1604f1 and 1604f2 respectively. The two brackets 1602f1 and 1602f2 are connected to the first portion 1612f1. In the present example, the light

fixtures 1600f1 and 1600f2 are not dynamic and their directions or angles of light focus are fixed. Hence, they may have the design of the light fixture 1500a, 1500b or 1500c of Fig. 15A to 15C. In another example, they may be configured to be dynamic and may have the design of the light fixture 1600b, 1600c, 1600d, or 1600e of Fig. 16B to 16E. An actuator 1606f such as a motor is configured to, under user control, rotate the first portion 1612f1 360 degrees about the longitudinal axis 1618f of the first portion 1612f1. A gear system 1610f is provided to enable the rotation of the first portion 1612f1 to be done. Light direction and angle of the light emitted from the two light fixtures 1600f1 and 1600f2 can be changed by controlling the actuator 1606f to rotate the two light fixtures 1600f1 and 1600f2.

Fig. 16G shows a side view of a second example of a rotating motion light assembly 1600g. The light assembly 1600g has a ceiling plate 1614g for installing to a surface, which for this example, is preferably a ceiling surface. When installed on the ceiling, the light assembly 1600g would have a pendant (top down) design. A central shaft 1612g is connected to the ceiling plate 1614g. The central shaft 1612g is configured to be stationary and connected to a section 1616g. The section 1616g is movably coupled to a center point of a rotating mechanism (or platform) 1610g. The rotating mechanism 1610g may in top or bottom view be a circular platform or be an elongate shaft. Two (plant grow-light) light fixtures 1600g1 and 1600g2 are disposed closed to opposite ends of the rotating mechanism 1610g. The two light fixtures 1600g1 and 1600g2 extend from the rotating mechanism 1610g in a same direction that is parallel relative to a longitudinal axis 1618g of the central shaft 1612g. In the present example, the light fixtures 1600g1 and 1600g2 shines light downwards. The light fixtures 1600g1 and 1600g2 are pivotably mounted to two brackets 1602g1 and 1602g2 respectively and are configured to be pivotable about two pivots 1604g1 and 1604g2 respectively. In the present example, the light fixtures 1600g1 and 1600g2 are not dynamic and their directions or angles of light focus are fixed. Hence, they may have the design of the light fixture 1500a, 1500b or 1500c of Fig. 15A to 15C. In another example, they may be configured to be dynamic and may have the design of the light fixture 1600b, 1600c, 1600d, or 1600e of Fig. 16B to 16E. An actuator 1606g such as a motor is configured to, under user control, rotate the rotating mechanism 1610g 360 degrees about the longitudinal axis 1618g of the central shaft 1612g. A gear system (not shown) may be provided to enable the rotation of the rotating mechanism 1610g to be done. Light direction and angle of the light emitted from the two light fixtures 1600g1 and 1600g2 can be changed by controlling the actuator 1606g to rotate the two light fixtures 1600g1 and 1600g2. In another example, the central shaft 1612g may be made to rotate together with the rotating mechanism 1610g.

Planters B and C are examples of horizontal areas of greenery. Examples of proposed lighting systems for a vertical green wall or surface are described as follow.

Fig. 11A shows a front view 1104 and a side view 1106 of a first example of a lighting system 1100 for a vertical green wall or surface 1102. The lighting system 1100 is a static installation with no moving parts. The green wall 1102 is squarish in shape having dimensions of 3600 mm by 3600 mm. The proposed lighting system 1100 comprises a plurality of light fixtures 1108 mounted in line array or arrangement, which is parallel to the horizontal side of the green wall 1102. The plurality of light fixtures 1108 are modular in design. 8 modules of the light fixtures 1108 (numbered 1 to 8 in Fig. 11A) with each module having a length of 800 mm are combined to form 2 rows, one upper row and one lower row. Each row has 4 modules. Each module is rectangular in shape, similar to the light fixtures 1302 and 1304 of Fig. 13A and 13B respectively.

The plurality of light fixtures 1108 are mounted to brackets 1110 that are mounted to a ceiling. The height of the plurality of light fixtures 1108 from the ground is 3800 mm. The horizontal distance of the plurality of light fixtures 1108 to the plant surface of the green wall 1102 is 800 mm. 800

- mm is considered short so the Ingress Protection rating for the light sources, preferably LEDs (for protection against water and high humidity) may be set as IP65. The CCT of the light output may be set as white output of 3800K, with CRI greater than 90 and R9 lesser than 90. Shielding of the light output should be implemented to try to achieve UGR of lesser than 19 (the lower the better but not compromising on plant growth) to provide viewing comfort. The lighting system 1100 comprises a processor or controller for dimming control and/or scene control, which may be programmed so as to create different ambience for different times of the day or for different purposes required of the green space (e.g. entertainment purposes). The power rating of each module of light fixture 1108 for this example is 96W.
- Based on the proposed method of making the lighting system, the PPFD value targets and range to meet is important to ensure that the plants can grow. Parameters like plant size and plant density / porosity for understanding the required light penetration to reach lower layers of the plants should be studied and considered. The database created by the inventors of the invention described herein contains data of over 5 years of plants growing without sunlight across 300 species, including hibiscus, orchids, aloe vera, lavender, geranium etc., which were previously known to be impossible without sunlight. The data of many other species are also gathered from other sources.
- Based on the understanding of the data stored in the earlier described database, the preferred average PPFD values for such vertical green wall is determined to be in the range of 50 to 80 $\mu\text{mol m}^{-2} \text{s}^{-1}$, with some spots or areas requiring greater than 100 $\mu\text{mol m}^{-2} \text{s}^{-1}$ if there are flowering plants. Such spots or areas would require light to be focused by one or more of the light sources of the light fixtures used. The green wall may be provided with a plurality of buckets or pots of plants with leaves of varying density.
- The plurality of light fixtures 1108 and/or the light sources contained within the light fixtures 1108 have to be adjusted to shine light at all areas of the vertical green wall, with intensity adjusted depending on the PPFD requirements to be met for each area. Through software simulation, the Lux profile of light projected on the green wall 1102 that is provided by the plurality of light fixtures 1108 is shown in a heat map in Fig. 11B. The corresponding PPFD profile converted from the Lux profile via predetermined conversion factors is shown in a heat map in Fig. 11C. Overall, it can be seen that the PPFD requirements are largely met for the green wall 1102 and the lighting result provided by the lighting system 1100 of Fig. 11A is satisfactory. An example of a table (table 5) containing data relating to conversion factors for each module of the lighting fixtures 1108 is as follow. Note that appropriate equations and formulas may be determined from the data of table 5 and a calculator applying such equations and formulas can be provided to users to easily work out the values of the parameters.

Table 5: Peak PPFD values at distances away from light source and at specific effective beam angle (degrees)

Distance (m = meter) / Effective Beam angles (degrees)	5degrees on each side of central optical axis	8degrees on each side of central optical axis	14.5 degrees on each side of central optical axis	22degrees on each side of central optical axis	6x 27 (Asymmetric; 6degrees on one side of central optical axis and 27 degrees on the other side)
1m	623	437	327	133	173
2m	251	158	107	46	67
3m	141	81	51	20	36

4m	90	49	30	12	22
5m	74	33	19	7	15

Examples of how the table 5 above should be read is as follow. For instance, the peak PPFD value of 14.5 degrees on each side of central optical axis (i.e. total light beam angle = $14.5 \times 2 = 29$ degrees) at 2 meters is $107 \mu\text{mol m}^{-2} \text{s}^{-1}$ and the peak PPFD value of 5 degrees on each side of central optical axis (i.e. total light beam angle = $5 \times 2 = 10$ degrees) at 4 meters is $90 \mu\text{mol m}^{-2} \text{s}^{-1}$. The data of table 5 can help to determine the range of effective beam angles required to target different heights and areas. The energy or power utilisation is the same for each light source but the intensity and coverage would differ after adjusting / adding secondary optics, adding shielding members, and/or setting different beam angles for different distances.

Fig. 12A shows a front view 1204 and a side view 1206 of a first example of a lighting system 1200 for a vertical green wall or surface 1202. The lighting system 1200 is a dynamic installation with moving parts. It can be said to be a scaled up version of the lighting system of planter C and has all the benefits of the earlier described example for planter C. The green wall 1202 is squarish in shape having dimensions of 3600 mm by 3600 mm. The proposed lighting system 1200 comprises a plurality of light fixtures 1208 mounted in line array or arrangement, which is parallel to the horizontal side of the green wall 1202. The plurality of light fixtures 1208 are modular in design. 4 modules of the light fixtures 1208 (numbered 1 to 4 in Fig. 12A) with each module having a pitch of 800mm are interconnected to form one row. The light fixture 1208 of each module can be circular in shape, similar to the light fixtures 1306 and 1308 of Fig. 13C and 13D respectively.

In the lighting system 1200 of Fig. 12A, only one SDLD mechanism similar to the SDLD mechanism 710 of Fig. 7A is used. In another example, more than one SDLC mechanisms may be used, for instance, 4 SDLD mechanisms can be used to move the four light fixtures 1208 in the lighting system 1200 of Fig. 12A. Each of the light fixtures 1208 is similar to the light fixture 704 of Fig. 7A. However, the wattage of each light fixture 1208 is higher at 96W instead of 17.5W of the light fixture 704 so as to provide enough light intensity to light up the vertical green wall 1202, which has larger planting surface than planter C. The wattage of the single SDLD mechanism for moving four light fixtures 1208 in Fig. 12A is about 15W. The four light fixtures 1208 are mounted on one continuous rail with a light fixture pitch of 800mm (i.e. each light fixture is about 800mm from the next light fixture). In the present example, all four light fixtures 1208 are moved together (synchronously) for a path distance of 700mm (including movement distance to the left and the right). In another example, the movements of different light fixtures may not be synchronous.

The plurality of light fixtures 1208 are mounted to brackets 1210 that are mounted to a ceiling. The height of the plurality of light fixtures 1208 from the ground is 3800 mm. The horizontal distance of the plurality of light fixtures 1108 to the plant surface of the green wall 1102 is 700 mm. 700 mm is considered short so the Ingress Protection rating for the light sources, preferably LEDs (for protection against water and high humidity) may be set as IP65. The CCT of the light output may be set as white output of 3800K, with CRI greater than 90 and R9 lesser than 90. Shielding of the light output should be implemented to try to achieve UGR of lesser than 19 (the lower the better but not compromising on plant growth) to provide viewing comfort.

The lighting system 1200 comprises a processor or controller for controlling the movements of the light fixtures 1208 (e.g. control movement speed and movement cycle), dimming and/or scene control, which may be programmed so as to create different ambience for different times of the day or for different purposes required of the green space (e.g. entertainment purposes). As there is lesser number of light fixtures used compared to the case of Fig. 11A, the power consumption

of the lighting system 1200 is much lesser than that of the lighting system 1100. The lighting system 1100 of Fig. 11A may also comprise a processor or controller for dimming control and/or scene control, which may be programmed so as to create different ambience for different times of the day or for different purposes required of the green space (e.g. entertainment purposes).
 5 The mood setting and entertainment features are optional.

The processor or controller can be configured to adjust movement parameters of the plurality of light fixtures 1208 collectively, since they are moving synchronously. In another example, if four SDLD mechanisms are being used to move each light fixture 1208 separately, the movement
 10 parameters of each of the light fixtures can be adjusted individually. The movement parameters can include pre-determined length of movement of each light fixture 1208, movement speed of each light fixture 1208 and number of movement cycles of each light fixture 1208. A cycle refers to moving from any point in the movement path of the light fixture 1208 along the rail of the SDLD mechanism back to the same point (e.g. with reference to Fig. 7A, from position A back to position
 15 A or position B back to position B), which in the present example is a distance of $700\text{mm} \times 2 = 1400\text{mm}$. A preferred starting point of each light fixture 1208 is at the middle of the rail of the SDLD mechanism (e.g. with reference to Fig. 7A, the midpoint or halfway point between position A and position B). Like the example of planter C, for optimum plant growth effect in an indoor environment with little or no sunlight, the preferred movement parameters configured for each
 20 light fixture 1208 of Fig. 12A is 3 cycles (covers about distance of $1400\text{mm} \times 3 = 4200\text{mm}$) in 12 hours, which works out to be movement speed of about 0.097 mm/s . For the example of Fig. 12A, the following parameters of the SDLD mechanism may be controlled by the processor or controller, Displacement (distance to move), Tilt angle of each light fixture 1208, Time duration of movement of each light fixture 1208, Speed of movement of each light fixture 1208, Start / Stop / Return
 25 commands to start or stop movement or to instruct each light fixture 1208 to return to a pre-determined "home" position (e.g. midpoint of the rail), and Number of Cycles of each light fixture 1208 (e.g. one cycle may be a movement path starting from a home position and ending at the home position). In another example involving rotational motion, another parameter, Arc distance relating to curved/circular movements of light fixtures may be controlled by the processor or
 30 controller.

The plurality of light fixtures 1208 and/or the light sources contained within the light fixtures 1208 have to be adjusted to shine light at all areas of the vertical green wall, with intensity adjusted depending on the PPFD requirements to be met for each area. Through software simulation, the
 35 instantaneous PPFD profile of the light projected on the green wall 1202 that is provided by the light fixtures 1208 at their positions in Fig. 12A is shown a heat map in Fig. 12B. The time-averaged Lux profile over a motion cycle of the light fixtures 1208 of the light projected on the green wall 1202 is shown in a heat map in Fig. 12C. The corresponding time-averaged PPFD profile converted from the time-averaged Lux profile via predetermined conversion factors is
 40 shown in a heat map in Fig. 12D. Overall, it can be seen that the PPFD requirements of the green wall 1102 are better met compared to the green wall 1202. However, there are intensive lighting hotspots in the case of the lighting system 1100 of Fig. 11A that can be better utilized and distributed. The lighting result provided by the lighting system 1200 of Fig. 12A is promising as it addressed that using only half the number of fixtures translating to an immediate 50% reduction
 45 in all costs.

Both the lighting systems 1100 and 1200 are examples of lighting systems created by the proposed method of the present disclosure. However, the lighting system 1200 is better in terms of efficiency and energy consumption as can be seen from the calculations below. In the
 50 calculations, one light fixture uses 96W. There are 8 light fixtures in lighting system 1100 and 4

light fixtures in lighting system 1200. For easy calculation, 1 light fixture is taken to cost about \$1000.

System efficiency (PPFD/\$) for lighting system 1200:

- 5 67 is the average PPFD across the entire planting bed 1202 of the lighting system 1200.
4 light fixtures costs \$4000. It is projected that installation and material costs for the SDLD mechanism plus 4 light fixtures (including labour and cabling works) is equivalent to the costs for 8 light fixtures. Therefore, the SDLD mechanism is not considered in the calculations below: $67/4000 = 0.01675$ PPFD/\$

- 10 System efficacy (PPFD/W) for lighting system 1200:

4 light fixtures uses 384W.

The SDLD mechanism uses 15W.

$67/399 = 0.1679$ PPFD/W

- 15 System efficiency (PPFD/\$) for lighting system 1100:

100 is the average PPFD across the entire planting bed 1102 of the lighting system 1100.

8 light fixtures costs \$8000. $100/8000 = 0.0125$ PPFD/\$

System efficacy (PPFD/W) for lighting system 1100:

- 20 8 light fixtures uses 768W.

$100/768 = 0.13$ PPFD/W

In the examples of vertical green wall implementations above, a plurality of plant types of different and wide varieties can be placed randomly in the vertical green walls 1102 and 1202. Some examples are Monstera, Aloe Vera, Anthurium, Hibiscus, Orchid, Ferns, Valentine, Burle Marx, Peacock Plant, Silver vine, Spider Plant, Silver Queen, Japanese Rose, Philodendrons, Scandens, Devil's Backbone, and many more. Similarly, such plants can also be grown in a horizontal planter.

- 30 Limited adoption of indoor greenery, particularly in spaces with minimum natural light, can be attributed to a multitude of challenges that collectively discourage its widespread embrace. These challenges include the following:

- 35 1. Insufficient Natural Light: Many indoor environments lack the requisite natural sunlight essential for healthy plant growth. This deficiency necessitates the use of artificial lighting solutions. Conventional artificial lighting solutions are costly and not optimised for both plant growth and plants viewing.
2. High initial investment cost, a deterrent: High initial light equipment setup cost and little know-how, resulting in use of more fixtures, more installation costs and more upfront costs.
40 3. High recurring electrical cost: To compensate for the absence of natural light, high artificial light intensity is required with long operating hours and continuous lighting during the photoperiod.
4. Unsustainable: High energy consumption and high carbon emission. It costs more to have plants especially if they cannot survive or survive for long.
5. High manpower costs: High resource-intensive maintenance.
45 6. High maintenance costs, if unsuccessful: This fear of incurring substantial maintenance costs in the event of unsuccessful indoor greenery, as well as the embarrassment and disruption during the rectification period, can deter one from attempting biophilic designs..
7. Lack of knowledge and expertise: Successful indoor greenery requires expertise in various disciplines, including architecture, landscaping and lighting. Many individuals and organizations
50 lack the interdisciplinary knowledge needed to create thriving indoor plant environments. This knowledge gap can lead to unsuccessful attempts.

8. Limitations of existing plant growth lights today: The energy consumption efficiency and efficacy are not optimised, light output colour and light intensity are not for pleasant viewing and only focused on plant growth yield and harvesting, and not suitable for applications other than plant growth at close range.
- 5 9. Restriction in creativity and design: Difficult to apply to attain pleasant viewing in biophilic designs indoors. Not customizable or not easy to customize.
10. Perceived difficulty: Perceived complexity in the construction of indoor greenery, coupled with the scarcity of successful reference cases.
- 10 Examples of the present disclosure try to overcome the challenges stated above through the following.
1. Sunlight Replacement:
A range of carefully engineered pre-formulated plant growth light spectrums is designed to serve as effective substitutes for sunlight across various applications for both human illumination (i.e. provide lighting for human spaces, plant growth and allow pleasant plants viewing) and for plant growth. They are particularly useful in situations where natural sunlight is lacking or insufficient for optimal plant growth. In examples of the present disclosure, a proposed lighting system can be configured to have a processor or controller execute instructions to enable selection of a specific light recipe from a plurality of plant growth light recipes that is suitable for both pleasant human viewing and for plant growth. They may vary in terms of colour temperature and intensity.
2. Cost efficient Solution:
If dynamic light fixture is used, only half the lighting equipment is needed compared to having only static lighting equipment. Examples of the present disclosure provide a scalable intelligent system customizable and configured to light up a given target coverage area. Half the installation cost and half the maintenance cost are also expected if dynamic light fixture is used. These benefits significantly reduce financial barriers. Additionally, there is inherent efficiency to utilize a single set of lighting equipment for human illumination, plant growth, and even for entertainment purposes. There is no requirement for the installation of three distinct layers of light fixtures i.e. for human illumination, plant growth, and entertainment. The power consumption allocated to human illumination and entertainment seamlessly complements the power consumption needed for plant growth. This synergy ensures optimal resource utilization and sustainability. Overall, the proposed lighting solution according to examples of the present disclosure provides a substantial energy-saving advantage.
3. Reduced Energy Consumption and Environmental Impact:
This is achieved by having about half the lighting equipment (compared to the lighting equipment required for cases like planter B) and half the electricity operating cost. As a result, the carbon footprint is also halved. Power consumption is maximised and environmental impact is significantly reduced.
4. Minimized Manpower Costs:
- The proposed lighting system of examples of the present disclosure is made from research based calculated strategies and solutions, which reduces reliance on extensive or skilled manpower to work them out. For instance, a database containing prescribed parameters for different input parameters and/or pre-determined conversion or correction factors for converting PPFD and Lux is provided to facilitate the process of making the proposed lighting system.
- The proposed lighting system works well and will reduce the need for frequent replacement of plants or trees as they will be healthy.
- The proposed lighting system provides good light distribution and will reduce the need to prune the plants due to shadowing or uneven growth towards static light sources.
- The proposed lighting system can help plants to grow healthily and there will be reduced need to rotate plants in and out of a plant nursery due to provision of insufficient artificial lighting.
- There will be reduced need to move plants towards sunlight areas for survival.

- There will be reduced need to rotate a plant's position towards a window or opening to capture some natural light.
- The manpower required to perform the labour intensive tasks above is not scalable. However, the proposed lighting system is scalable.
- 5 - Fixture maintenance frequency is significantly reduced if dynamic fixtures are used as lesser fixtures are used.
- 5. Confidence in Success: Tangible plant growth results as demonstrated by the examples of planters A to C will instil confidence that having indoor/sheltered greenery is affordable and achievable.
- 10 6. Knowledge Sharing Increases Expertise: The research based calculated strategies and solutions i.e. knowledge database used during the making of the proposed lighting system addresses lack of interdisciplinary knowledge required for thriving indoor greenery. All the research, deep understanding, and experience are realised in the form of the knowledge database. With this database, knowledge can shared easily during the making process of the lighting system, and this will facilitate successful installations of precisely calculated systems.
- 15 7. Versatile Configurations:
For the proposed lighting system, 3 categories of plant growth light spectrums are created to cater to every need and application, with different form factors, different wattages, different beam angles, different mounting accessories, mixed plant growth light spectrums, Ingress Protection (IP) ratings, option for visual comfort accessories, and different light control options, thereby providing more than 10,000 possibilities.
- 20 8. The versatile configurations mentioned above allow freedom in creativity and design of the proposed lighting system during the making of the lighting system.
- 9. Proven Success:
25 The experiments conducted for planters A to C show that the proposed lighting system is a scalable system solution that can address concerns from human, plants, community and the environment.
- 30 It should be noted that although compared to the planter C example, the planter B example loses out in terms of costs, energy consumption and plant maintenance (i.e. more plant trimming or plant pots relocation are required due to overgrowth), it still provides light for pleasant viewing and plant growth light, configured to be disposed at a distance not obstructing viewing of the plants and designed with PPFD optimization in mind. Furthermore, each light fixture comprises light sources designed in a manner according to the examples of Fig. 13A to 13D, wherein light angling or tilting of each individual light source for even light spread and good light colour blending effect can be achieved.
- 35 The lighting system of planter B can also comprise the earlier mentioned processor or controller to enable parameters like light intensity of its light sources to be adjusted. For instance, in the case of the circular light fixtures of Fig. 13C and 13D, light sources located in the center of each light fixture may be dimmed to reduce the impact of overgrowth of plants directly under the light sources. The processor or controller may be configured to execute instructions of software or firmware to enable adjustment of angle or tilt of lights sources, or to enable a light show for entertainment purposes to be performed.
- 40 45 Hence, while the planter B example is not a preferred embodiment compared to the planter C example, it is still a viable solution to be proposed for providing good light distribution and good light colour blending for pleasant viewing as well as plant growth.
- 50 In view of disclosures above, a base strategy for providing sufficient PPFD can be as follows. Firstly, use a PPFD intensity heat (or contour) map to optimize light fixture locations. Secondly,

optimise light fixture beam and internal angles (i.e. via tilting or angling of light source angles) to achieve effective PPFD coverage and area. PPFD uniformity can be achieved through optimised fixture tilt angle, optimised fixture wattage, and optimised fixture quantity. The main objective is to achieve system efficiency (PPFD/\$) and efficacy (PPFD/W).

5

Some possible applications of the lighting systems of examples of the present disclosure are as follow. The proposed lighting system and plant bed can be installed at or implemented in:

1. At any space devoid of sunlight or with insufficient sunlight. The premises can be, for instance, in commercial buildings, hotels, restaurants, supermarkets, hospitals, recovery centers, nursing
- 10 homes, offices, banks, private homes, exhibition and events, theme parks and atriums.
2. Any indoor or sheltered area for increasing food production i.e. Indoor farming. Such farming may be commercial or home based.
3. Plant-based Product Manufacturers (food, beauty, treatments).
4. Any industrial premises that should provide clean air for workers.
- 15 5. Underground cities.
7. Indoor or sheltered vertical farming places.
8. An area for indoor or sheltered algae and microalgae cultivation.
9. Places for conducting plant growth research and development.
10. Premises of Educational Institutions.
- 20 11. Premises of companies who invest in ESG (Environmental, Social and Governance).
12. Places for cultivation of medicinal plants and herbs for Biotechnology and/or Pharmaceutical use.
13. Indoor or Sheltered areas of Botanical Gardens
14. Underwater, for instance, in large aquariums. Aquatic plants would be grown in this case.
- 25 The places mentioned above may allow public access and/or have secured access (private).

Examples of the present disclosure may comprise the following features. Reference numerals of the elements in the figures of the present disclosure that are examples of the features discussed are provided in brackets.

30

A method (e.g. Fig. 1) for making a lighting system (e.g. 600, 700, 1100, 1200, 1600f and 1600g) for plant growth and viewing, the method comprising:

- receiving parameters including one or more plants to grow and size of an area (e.g. 602, 702, 1102 and 1202) provided for placing the one or more plants to be grown;
- 35 determining photosynthetic photon flux density (PPFD) required for growing the one or more plants;
- disposing one or more light fixtures (e.g. 604a, 604b, 704, 1108 and 1208, 1400, 1500a, 1500b, 1500c, 1600a, 1600b, 1600c, 1600d, 1600e, 1600f1, 1600f2, 1600g1 and 1600g2) comprising a plurality of light sources (e.g. W, B, R, W/R, and W/B) to direct light
- 40 at the one or more plants to provide the required PPFD; and
- configuring the plurality of light sources to focus light at different parts (e.g. Zones 1 to 4) of the one or more plants to provide even distribution of the light directed at the one or more plants,
- 45 wherein the plurality of light sources is configured to emit a spectrum of light, including coloured light and white light for masking the coloured light to enable plant growth and pleasant viewing of the one or more plants,
- wherein the plurality of light sources is disposed at a distance away from the one or more plants, not obstructing viewing of the one or more plants.

For example, the white light can be produced from a blend of coloured lights and/or provided by purely or mainly white light sources. It is understood that the plants can include just one type of plant, different species of the same plant and/or different species of different plants.

- 5 The method may comprise:
 configuring the plurality of light sources to move in a predetermined manner to focus light evenly on different parts of the one or more plants.

- The method may comprise:
 10 accessing a database containing data correlating prescribed parameters to the parameters to be received; and
 determining based on the data, for the received parameters, the prescribed parameters of the one or more light fixtures and/or the plurality of light sources to be used to provide the required photosynthetic photon flux density (PPFD).

- 15 The method may comprise:
 calculating an average PPFD value for the one or more plants; and
 determining a least number of the one or more light fixtures to be used to achieve the average PPFD.

- 20 The method may comprise:
 setting movement parameters of the one or more light fixtures and/or the plurality of light sources so as to move one or more of the plurality of light sources in a predetermined manner to focus light evenly on different parts of the one or more plants.

- 25 The method may comprise:
 providing instructions to control the plurality of light sources to concentrate on plant growth for a predetermined time period, wherein during the predetermined time period, the white light will not mask or will mask lesser of the coloured lights.

- 30 The method may comprise:
 providing instructions to change light beam shape of one of the plurality of light sources to adjust light coverage on a part of the one or more plants.

- 35 The method may comprise:
 providing instructions to adjust lighting parameters including light intensity, time duration of lighting, and light colour of the plurality of light sources to achieve one or more lighting effects.

- 40 The method may comprise:
 conducting a computer graphics simulation of a lighting system constructed based on any one of the preceding claims to facilitate optimisation of the lighting system.

- 45 A lighting system (e.g. 600, 700, 1100, 1200, 1600f, and 1600g) for plants viewing, wherein the lighting system comprises:

- one or more light fixtures (e.g. 604a, 604b, 704, 1108 and 1208, 1400, 1500a, 1500b, 1500c, 1600a, 1600b, 1600c, 1600d, 1600e, 1600f1, 1600f2, 1600g1 and 1600g2) comprising a plurality of light sources to direct light at one or more plants located in a provided area (e.g. 602, 702, 1102 and 1202) to provide predetermined photosynthetic photon flux density (PPFD) required for growing the one or more plants,
 50 wherein the plurality of light sources (e.g. W, B, R, W/R, and W/B) is configured to:

focus light at different parts (e.g. Zones 1 to 4) of the one or more plants to evenly distribute the light directed at the one or more plants; and
 emit a spectrum of light, including coloured light and white light for masking the coloured light to enable plant growth and pleasant viewing of the one or more plants, and
 wherein the plurality of light sources is disposed at a distance away from the one or more plants, not obstructing viewing of the one or more plants.

The lighting system may comprise:
 one or more actuators (e.g. 702, 1606a, 1606b, 1606c, 1606d, 1606e1, 1606e2, 1606f, and 1606g) configured to move the one or more light fixtures in a predetermined manner to focus light evenly on different parts of the one or more plants.

The one or more actuators may be configured to move the one or more light fixtures in a predetermined path.

The one or more actuators may be configured to pivot the one or more light fixtures and/or one or more of the plurality of light sources about one or more pivots (e.g. 1504a, 1504b1, 1504b2, 1504c1, 1504c2, 1504c3, 1604a, 1604b, 1604c, 1604d1, 1604d2, 1604e1, 1604e2, 1604e3, 1604f1, 1604f2, 1604g1, and 1604g2) to focus light at different angles or directions.

The one or more actuators may be configured to move one or more of the light fixtures at a speed of 0.001 to 800 mm per second.

The number of the one or more light fixtures to use may be determined by:
 calculating an average PPFD value for the one or more plants; and
 determining the least number of the one or more light fixtures to be used to achieve the average PPFD.

The lighting system may comprise:
 a processor configured to execute instructions in a memory to adjust lighting parameters of the plurality of light sources including light intensity, time duration of lighting, and light colour, to achieve one or more lighting effects.

One of the one or more lighting effects may comprise:
 a setting such that the plurality of light sources concentrates on plant growth for a predetermined time period, wherein during the predetermined time period, the white light will not mask or will reduce masking of the coloured lights.

The processor may be programmable to change light beam shape of one or more of the plurality of light sources to adjust light coverage on one or more parts of the one or more plants.

The processor may be programmable to adjust movement parameters including movement speed of the plurality of light sources or parameters determining how the plurality of light sources moves or tilts.

The spectrum of light may meet requirements of Colour Rendering Index (CRI) of greater than 90 and R9 colour rendering value (R9) of greater than 90.

The one or more light fixtures may be configured to achieve a Unified Glare Rating of 19 or less.

It may be that no blue Light Emitting Diode (LED) is used in the plurality of light sources.

- The one or more light fixtures may be configured to shield the plurality of light sources to provide 40 degrees or more cut off angle to reduce glare from the light emitted by the plurality of light sources.
- 5 The plurality of light sources may be arranged linearly in one or more rows.
- The plurality of light sources may be arranged in a circular array.
- 10 In some examples, the plurality of light sources may be arranged in other patterns or tessellations.
- One or a group of the light sources in one light fixture of the one or more light fixtures may be directed at a different angle from another one or group of the light sources in said light fixture.
- 15 The one or more light fixtures comprising the plurality of light sources may be modular in design and scalable to cater to different power requirements.
- The one or more light fixtures may be configured to have frontal access to the plurality of light sources to enable easy adjustment and/or replacement of the plurality of light sources.
- 20 Each of the plurality of light sources may comprise secondary optics (e.g. 1404) adjustable to focus light emitted at predetermined parts of the one or more plants.
- The distance (of the plurality of light sources) away from the one or more plants may be 700 mm to 18 metres.
- 25 In the present disclosure, unless the context clearly indicates otherwise, the term "comprising" has the non-exclusive meaning of the word, in the sense of "including at least" rather than the exclusive meaning in the sense of "consisting only of". The same applies with corresponding grammatical changes to other forms of the word such as "comprise", "comprises" and so on.
- 30 While the invention has been described in the present disclosure in connection with a number of examples, embodiments and implementations, the invention is not so limited but covers various obvious modifications and equivalent arrangements, which fall within the purview of the appended claims. Although features of the invention are expressed in certain combinations among the claims, it is contemplated that these features can be arranged in any combination and order.
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Claims

1. A method for making a lighting system for plant growth and viewing, the method comprising:
 - 5 receiving parameters including one or more plants to grow and size of an area provided for placing the one or more plants to be grown;
 - determining photosynthetic photon flux density (PPFD) required for growing the one or more plants;
 - 10 disposing one or more light fixtures comprising a plurality of light sources to direct light at the one or more plants to provide the required PPFD; and
 - configuring the plurality of light sources to focus light at different parts of the one or more plants to provide even distribution of the light directed at the one or more plants, wherein the plurality of light sources is configured to emit a spectrum of light, including coloured light and white light for masking the coloured light to enable plant growth and pleasant viewing of the one or more plants,
 - 15 wherein the plurality of light sources is disposed at a distance away from the one or more plants, not obstructing viewing of the one or more plants.
2. The method of claim 1, the method comprising:
 - 20 configuring the plurality of light sources to move in a predetermined manner to focus light evenly on different parts of the one or more plants.
3. The method of claim 1 or 2, the method comprising:
 - 25 accessing a database containing data correlating prescribed parameters to the parameters to be received; and
 - determining based on the data, for the received parameters, the prescribed parameters of the one or more light fixtures and/or the plurality of light sources to be used to provide the required photosynthetic photon flux density (PPFD).
- 30 4. The method of claim 1, 2 or 3, the method comprising:
 - calculating an average PPFD value for the one or more plants; and
 - determining a least number of the one or more light fixtures to be used to achieve the average PPFD.
- 35 5. The method of any one of the preceding claims, the method comprising:
 - setting movement parameters of the one or more light fixtures and/or the plurality of light sources so as to move one or more of the plurality of light sources in a predetermined manner to focus light evenly on different parts of the one or more plants.
- 40 6. The method of any one of the preceding claims, wherein the method comprises:
 - providing instructions to control the plurality of light sources to concentrate on plant growth for a predetermined time period, wherein during the predetermined time period, the white light will not mask or will mask lesser of the coloured lights.
- 45 7. The method of claim 5 or 6, wherein the method comprising:
 - providing instructions to change light beam shape of one of the plurality of light sources to adjust light coverage on a part of the one or more plants.
8. The method of claim 5, 6 or 7, wherein the method comprising:

providing instructions to adjust lighting parameters including light intensity, time duration of lighting, and light colour of the plurality of light sources to achieve one or more lighting effects.

- 5 9. The method of any one of the preceding claims, the method comprising:
conducting a computer graphics simulation of a lighting system constructed based
on any one of the preceding claims to facilitate optimisation of the lighting system.
- 10 10. A lighting system for plant growth and viewing, wherein the lighting system comprises:
one or more light fixtures comprising a plurality of light sources to direct light at
one or more plants located in a provided area to provide predetermined photosynthetic
photon flux density (PPFD) required for growing the one or more plants,
wherein the plurality of light sources is configured to:
focus light at different parts of the one or more plants to evenly distribute the light
15 directed at the one or more plants; and
emit a spectrum of light, including coloured light and white light for masking the
coloured light to enable plant growth and pleasant viewing of the one or more plants, and
wherein the plurality of light sources is disposed at a distance away from the one
or more plants, not obstructing viewing of the one or more plants.
- 20 11. The lighting system of claim 10, wherein the lighting system comprises:
one or more actuators configured to move the one or more light fixtures in a predetermined
manner to focus light evenly on different parts of the one or more plants.
- 25 12. The lighting system of claim 11, wherein the one or more actuators are configured to move
the one or more light fixtures in a predetermined path.
- 30 13. The lighting system of claim 11 or 12, wherein the one or more actuators are configured
to pivot the one or more light fixtures and/or one or more of the plurality of light sources
about one or more pivots to focus light at different angles or directions.
- 35 14. The lighting system of any one of claims 11 to 13, wherein the one or more actuators are
configured to move one or more of the light fixtures at a speed of 0.001 to 800 mm per
second.
- 40 15. The lighting system of any one of claims 10 to 14, wherein the number of the one or more
light fixtures to use is determined by:
calculating an average PPFD value for the one or more plants; and
determining the least number of the one or more light fixtures to be used to achieve
the average PPFD.
- 45 16. The lighting system of any one of claims 10 to 15, wherein the lighting system comprises:
a processor configured to execute instructions in a memory to adjust lighting
parameters of the plurality of light sources including light intensity, time duration of lighting,
and light colour, to achieve one or more lighting effects.
- 50 17. The lighting system of claim 16, wherein one of the one or more lighting effects comprises:
a setting such that the plurality of light sources concentrates on plant growth for a
predetermined time period, wherein during the predetermined time period, the white light
will not mask or will reduce masking of the coloured lights.

18. The lighting system of claim 16 or 17, wherein the processor is programmable to change light beam shape of one or more of the plurality of light sources to adjust light coverage on one or more parts of the one or more plants.
- 5 19. The lighting system of any one of claims 16 to 18, wherein the processor is programmable to adjust movement parameters including movement speed of the plurality of light sources or parameters determining how the plurality of light sources moves or tilts.
- 10 20. The lighting system of any one of claims 10 to 19, wherein the spectrum of light meets requirements of Colour Rendering Index (CRI) of greater than 90 and R9 colour rendering value (R9) of greater than 90.
- 15 21. The lighting system of any one of claims 10 to 20, wherein the one or more light fixtures are configured to achieve a Unified Glare Rating of 19 or less.
22. The lighting system of any one of claims 10 to 21, wherein no blue Light Emitting Diode (LED) is used in the plurality of light sources.
- 20 23. The lighting system of any one of claims 10 to 22, wherein the one or more light fixtures is configured to shield the plurality of light sources to provide 40 degrees or more cut off angle to reduce glare from the light emitted by the plurality of light sources.
- 25 24. The lighting system of any one of claims 10 to 23, wherein the plurality of light sources is arranged linearly in one or more rows.
- 25 25. The lighting system of any one of claims 10 to 24, wherein the plurality of light sources is arranged in a circular array.
- 30 26. The lighting system of any one of claims 10 to 25, wherein one or a group of the light sources in one light fixture of the one or more light fixtures is directed at a different angle from another one or group of the light sources in said light fixture.
- 35 27. The lighting system of any one of claims 10 to 26, wherein the one or more light fixtures comprising the plurality of light sources is modular in design and scalable to cater to different power requirements.
- 40 28. The lighting system of any one of claims 10 to 27, wherein the one or more light fixtures is configured to have frontal access to the plurality of light sources to enable easy adjustment and/or replacement of the plurality of light sources.
- 45 29. The lighting system of any one of claims 10 to 28, wherein each of the plurality of light sources comprises secondary optics adjustable to focus light emitted at predetermined parts of the one or more plants.
- 50 30. The lighting system of any one of claims 10 to 29, wherein the distance away from the one or more plants is 700 mm to 18 metres.