

OPTIC DEVICE AND CULTIVATION SYSTEM USING THE OPTIC DEVICE

Technical Field

[0001] Embodiments generally relate to an optic device, and a cultivation system using the optic device. In particular, various embodiments relate to an optic device for redirecting Sunlight to lower and/or inner regions along a cultivation column (e.g. a cultivation rack, a cultivation tower, etc.), whereby the optic device and the cultivation column together form the cultivation system. More specifically, embodiments may relate to an optic device that may be used for farming or urban agriculture, by redirecting light from an edge of an upper cultivation tier (e.g. platform, plant bed etc.) of the cultivation column to shaded regions on a lower cultivation tier (e.g. lower-tier platform, plant bed etc.).

Background

[0002] In commercial greenhouses or outdoor farms, plants or other organisms (e.g. crops, seedlings and stem cuttings) may be cultivated on platforms (e.g. substantially horizontal platforms), also known as benches or beds (e.g. plant benches or plant beds).

[0003] On such platforms, the plants or other organisms may be grown or cultivated using methods, such as soil-based methods, any other suitable medium-based methods, or soil-less based methods (e.g. hydroponics or aeroponics). Typically, each of the platforms is deployed as a single-layered platform in a manner that permits them to be exposed to Sunlight. Deploying such platforms in the aforementioned single-layer fashion maximizes an amount of Sunlight (in other words, solar or light irradiation) that the plants or other organisms being cultivated on the platforms may be able to receive. However, large plots of land would be required to deploy the platforms in the single-layered fashion to achieve high crop yield.

[0004] In land-scarce regions, multiple platforms may be stacked vertically (e.g. one over another) to save space, for example, on a multi-tiered rack. That is, such multi-tiered racks may increase an effective cultivatable area, while occupying a same floor space as a single-layer platform. However, typically, in such multi-tiered racks, lower

or bottom platform(s) or tier(s) of the multi-tiered rack tend to receive less Sunlight during the day than upper or higher platform(s) or tier(s) overhead – especially during late mornings and early afternoon – due to the upper or higher platform(s) or tier(s) serving as physical obstructions that block a direct path of Sunlight from the Sun to the lower or bottom platform(s) or tier(s).

[0005] It has been found that cumulative direct solar irradiance based on solar elevation angles between 60° to 90° (i.e. degrees) may account for approximately 67% of a total incident solar energy (e.g. onto a platform or tier), particularly in tropical climates. As such, a significant amount of “free” Sunlight could potentially be untapped, for cultivating plants or organisms, as a result of upper or higher platform(s) or tier(s) of a multi-tiered rack acting blocking Sunlight to lower or bottom platform(s) or tier(s) of a multi-tiered rack.

[0006] Through various simulations performed, it has also been found that cumulative solar irradiation at a lower or bottom platform or tier of a multi-tiered rack (e.g. a two-tiered system) is significantly lower, than that with respect to a single-layered platform, for example, by up to 50-70% in a year. This means that one or more platform(s) or tier(s) added to a multi-tiered rack would pose limitations and constraints to cultivation of plants or other organisms on the lower or bottom platform(s) or tier(s) of the multi-tiered rack.

[0007] In order to increase an amount of useful photosynthetically active radiation (PAR) incident on lower platform(s) or tier(s) of a multi-tiered rack, artificial lighting is typically installed on the undersides of an upper or higher platform(s) or tier(s) of the multi-tiered rack. In particular, artificial lights, such as fluorescent lamps or light emitting diodes (LEDs), have been used to supplement natural PAR in a number of commercially-available systems. While crop yields of the plants or organisms being cultivated with such systems may be significantly increased with the help of the use of artificial lighting, such systems require significantly more electrical power than naturally powered (e.g. naturally lit) systems for cultivation of identical plants or organisms. The high electrical power consumption by such systems translate to high operational costs as well as leaving a high carbon footprint when the electrical power is derived from non-renewable resources.

[0008] Moreover, electrical devices in such systems generate and emit heat which radiate to the plants or organisms being cultivated. In order to maintain ideal

temperatures for cultivating the plants or organisms, specialized cooling systems or solutions are typically required. Among other issues accompanying specialized cooling systems or solutions, is increased operational costs.

[0009] Another conventional system being used today for plant or organism cultivation involves optical lenses or a combination of mirrors arranged to focus Sunlight onto a tiny-sized spot corresponding to one end of an optical fiber. At another end of the optical fiber, an emitter or diffuser device may be used to disperse the Sunlight. However, such a system tends to be difficult and expensive to install and to maintain.

[0010] Accordingly, there is a need for a simple and effective solution to improve lighting conditions for the shaded tiers of a multi-tiered rack (e.g. for plant or organism cultivation) which solve at least the above-stated issues.

Summary

[0011] According to various embodiments, an optic device is provided. The optic device includes a light-transmission unit, which includes a light-transmitting body. The light-transmitting body has a light-input surface for a light to enter the light-transmitting body and a light-output surface for the light to exit the light-transmitting body. The light-transmitting body also has a first planar side surface extending between the light-input surface and the light-output surface. The first planar side surface is adjoining the light-input surface at a first edge of the first planar side surface. The light-transmitting body also has a second planar side surface opposite to and parallel with the first planar side surface. The second planar side surface is adjoining the light-input surface at a first edge of the second planar side surface. The first edge of the first planar side surface and the first edge of the second planar side surface are parallel to each other and define a reference plane. The first planar side surface forms a non-zero acute internal angle with the reference plane. At least a region of the light-output surface is offset from at least a region of the light-input surface in an offset direction corresponding to a direction extending from the first planar side surface to the second planar side surface in a manner substantially parallel with the reference plane. The light-output surface includes a curved surface extending from a second edge of the first planar side surface and that curves away from the first planar side surface in the offset direction. The second edge

of the first planar side surface is opposite the first edge of the first planar side surface. The light-transmitting body is capable of redirecting a light entering the light-input surface with an entry angle within a range from 0° to 90° measured from a normal of the reference plane, which is corresponding to a range of angles from the normal to a line extending perpendicularly from the first edge of the first planar side surface to the normal, to exit from the light-output surface at an exit angle within a range from 180° to 270° measured from the normal of the reference plane.

[00012] According to various embodiments, a cultivation system is provided. The cultivation system includes a cultivation column having two or more cultivation tiers arranged along a column axis. The cultivation system further includes the optic device according to various embodiments. The optic device is coupled to a side of the cultivation column in a manner so as to form an overhang protruding from the side of cultivation column with the light-input surface of the light-transmitting body of the light-transmission unit of the optic device directed upwards with respect to the column axis of the cultivation column and the light-output surface of the light-transmitting body of the light-transmission unit of the optic device directed downwards with respect to the column axis of the cultivation column. The light-transmission unit of the optic device is capable of directing the light incident on the light-input surface of the light-transmitting body of the light-transmission unit of the optic device to irradiate an interior shaded space between two cultivation tiers of the two or more cultivation tiers of the cultivation column via the light-output surface of the light-transmitting body of the light-transmission unit of the optic device.

Brief description of the drawings

[00013] In the drawings, like reference characters generally refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the invention. In the following description, various embodiments are described with reference to the following drawings, in which:

FIG. 1 shows a schematic top view of a light-transmission unit of an optic device, according to various embodiments;

FIG. 2A shows a schematic side view of a first variant of a light-transmitting body of a light-transmission unit of an optic device, according to various embodiments;

FIG. 2B shows a schematic side view of a second variant of a light-transmitting body of a light-transmission unit of an optic device, according to various embodiments;

FIG. 2C shows a schematic side view of a third variant of a light-transmitting body of a light-transmission unit of an optic device, according to various embodiments;

FIG. 3A shows a schematic side view of a light-transmission unit which includes a plurality of light-transmitting bodies (e.g. the first variant of the light-transmitting bodies) forming a single unitary panel structure (i.e. a panel), according to various embodiments;

FIG. 3B is an image depicting simulation of light paths of Sunlight received and redirected by a light-transmission unit (e.g. a panel), according to various embodiments;

FIG. 4A is a perspective view of a cultivation system including a cultivation column with two cultivation tiers and at least one light-transmission unit (e.g. panel) mounted to at least one side of a topmost cultivation tier of the cultivation column, according to various embodiments;

FIG. 4B is an isolated perspective view of the light-transmission unit (e.g. panel) of FIG. 4A and an upward-facing surface of a bottom cultivation tier of the cultivation column of FIG. 4A, according to various embodiments;

FIG. 4C is a schematic side view of the light-transmission unit (e.g. panel) of FIG. 4A illustrating possible dimensions (in mm) of the light-transmission unit (e.g. panel), according to various embodiments;

FIG. 4D is a perspective view of a cultivation system including four cultivation columns, according to various embodiments;

FIG. 4E is a perspective view of a cultivation system including a cultivation column with three cultivation tiers, at least one light-transmission unit (e.g. panel) mounted to at least one side of a topmost cultivation tier of the cultivation column, and at least one light-transmission unit (e.g. panel) mounted to at least one side of a middle cultivation tier of the cultivation column, according to various embodiments;

FIG. 4F is a perspective view of a cultivation system including a cultivation column having at least six cultivation tiers and at least one light-transmission unit (e.g. panel) mounted to at least one side of a topmost cultivation tier of the cultivation column, according to various embodiments;

FIG. 5A show images depicting simulations of light paths of Sunlight incident on a cultivation column and at least one light transmission unit (e.g. panel) secured to a side of the cultivation column, when the Sun elevation is at 60°, 75°, and 90°, respectively, according to various embodiments;

FIG. 5B depict simulated and experimentally obtained “irradiance maps” based on light from a light source being redirected by a simulated/prototype light transmission unit (e.g. panel) which includes a plurality of light-transmitting bodies (e.g. the first variant of the light-transmitting bodies) onto a lower cultivation tier positioned 50 cm from the simulated/prototype light transmission unit (e.g. panel), when the incident light angle is at 60°, 75° and 90°, respectively, according to various embodiments;

FIG. 5C is a graph depicting solar angle with respect to redirection efficiency, based on a simulated/prototype light transmission unit (e.g. panel) which includes a plurality of light-transmitting bodies (e.g. the first variant of the light-transmitting bodies), according to various embodiments;

FIG. 5D and FIG. 5E depict simulated “irradiance maps” based on light from a light source being redirected by (i) a simulated light transmission unit (e.g. panel) which includes a plurality of the first variant of the light-transmitting bodies as well as by (ii) a simulated light transmission unit (e.g. panel) which includes a plurality of the second variant of the light-transmitting bodies, onto a lower cultivation tier positioned 50 cm from the simulated panel, when the incident light angle is at 60°, 75° and 90°, respectively, according to various embodiments;

FIG. 5F is a table showing uniformity ratios of light-transmitting body/bodies based on redirected irradiance on an area of interest; and

FIG. 6A and FIG. 6B show a prototype light transmission unit (e.g. panel), according to various embodiments;

FIG. 7A shows a perspective view of a prototype optic device with a light transmission unit (e.g. panel) and an attachment member which includes an extension element, according to various embodiments;

FIG. 7B to FIG. 7D show various views of a prototype optic device with a light transmission unit (e.g. panel) and an attachment member which includes a bracket;

FIG. 8A shows a set-up for conducting an experiment involving a prototype based on the light transmission unit (e.g. panel) of FIG. 3A, according to various embodiments; and

FIG. 8B is schematic side view depicting conditions for the experiment that involves the prototype based on the light transmission unit (e.g. panel) of FIG. 3A, according to various embodiments;

FIG. 8C shows the graphs of the measured Photosynthetic photon flux density values with respect to time at various positions from 10 cm to 50 cm, based on the experiment of FIG. 8B, according to various embodiments; and

FIG. 8D is a graph showing the cumulative photosynthetically active radiation (PAR) irradiation received at various positions along the width of the cultivation column of FIG. 8A, based on the experiment of FIG. 8B, according to various embodiments.

Detailed description

[00014] Embodiments described below in context of the apparatus are analogously valid for the respective method, and vice versa. Furthermore, it will be understood that the embodiments described below may be combined, for example, a part of one embodiment may be combined with a part of another embodiment.

[00015] It should be understood that the terms “on”, “over”, “top”, “bottom”, “down”, “side”, “back”, “left”, “right”, “front”, “lateral”, “side”, “up”, “down”, etc., when used in the following description are used for convenience and to aid understanding of relative positions or directions, and not intended to limit the orientation of any device, or structure or any part of any device or structure. In addition, the singular terms “a”, “an”, and “the” include plural references unless context clearly indicates otherwise. Similarly, the word “or” is intended to include “and” unless the context clearly indicates otherwise.

[00016] Various embodiments generally relate to optic devices (e.g. prismatic panels, or redirection devices) which may be capable of redirecting Sunlight or artificial light at an angle (e.g. an obtuse angle) with respect to a direction of the Sunlight or artificial light that enters the optic devices.

[00017] Various embodiments may also generally relate to optic devices which may be easy to manufacture or fabricate.

[00018] Various embodiments may also generally relate to one or more optic device(s) which may be simple and easy to set-up or install, in a modular manner, without any requirement for sophisticated technical skill. For example, the one or more optic device(s) may be easily attached or secured to a side of an external structure or fixture, such as a cultivation column, a platform (e.g. plant bed) of a multi-tiered rack, a side of a wall, a side of a building, etc.

[00019] Thus, one or more optic device(s) of various embodiments may be easily adapted or fitted (e.g. retrofitted) to an existing cultivation column (e.g. a multi-tiered rack, or any other rack or tower) for plant cultivation. Besides plant cultivation, the optic devices of various embodiments may be used for cultivating other photosynthetic organisms (e.g. algae and cyanobacteria), or may be employed in an aquaculture-related application. In another embodiment, the optic devices, according to various other embodiments, may be configured for illuminating living spaces (e.g. underground or indoor spaces, or between tall buildings).

[00020] The optic devices of various embodiments may be capable of redirecting and/or spreading and/or distributing the Sunlight or artificial light exiting the optic devices (e.g. via respective light-output surface(s) of the optic devices) over a relatively wide “distribution area” and/or with uniform irradiation across the distribution area. In other words, the optic devices of various embodiments may redirect or target Sunlight or artificial light towards a target or specific distribution area (e.g. an initially shaded zone or region) in a uniform manner across the distribution area, thereby increasing / improving cumulative photosynthetically active radiation (PAR) within that area. As a result of its light spreading and light distribution capabilities, installation of optic devices of various embodiments to an external structure or fixture may not require or involve tight tolerances (in other words, high precision or alignment) for the optic devices to illuminate an area by redirecting Sunlight or light thereto.

[00021] Moreover, according to various embodiments, as the optic devices may rely purely on Sunlight (without aid of electrically-powered artificial light) to perform light redirecting and light distribution functions, the optic devices of various embodiments may be environmentally friendly and easy to maintain.

[00022] FIG. 1 shows a schematic top view of a light-transmitting body 102 of a light-transmission unit 101 of an optic device 100, according to various embodiments. FIG. 2A shows a schematic side view of a first variant 102A of the light-transmitting body

(or body) 102 of the light-transmission unit 101 of the optic device 100, according to various embodiments. FIG. 2B shows a schematic side view of a second variant 102B of the light-transmitting body 102 of the light-transmission unit 101 of the optic device 100, according to various embodiments. FIG. 2C shows a schematic side view of a third variant 102C of the light-transmitting body 102 of the light-transmission unit 101 of the optic device 100, according to various embodiments.

[00023] According to various embodiments, there is provided the optic device 100. The optic device 100 may be configured for redirecting and/or distributing (or redistributing) a light. Specifically, at least a portion of light that enters the optic device 100 in a first direction may be redirected and/or distributed by the optic device 100 in a second direction different from the first direction. Specifically, the second direction may form an obtuse angle with the first direction.

[00024] The optic device 100 may include the light-transmission unit 101.

[00025] The light-transmission unit 101 of the optic device 100 may include at least one (in other words, one or more) body which may be capable of or configured for light transmission. Accordingly, the body may be the light-transmitting body 102. According to various embodiments, the light-transmitting body 102 may be made of or may include a light permeable (e.g. transparent or translucent) material, for example, glass (e.g. clear or tinted glass); polymer (e.g. engineering polymer, such as polycarbonate (PC), polymethylmethacrylate (PMMA) and polydimethylsiloxane (PDMS), which may possess high transmission efficiencies in the visible light spectrum); ceramic(s) (e.g. light transmitting ceramic(s)), etc. In particular, according to various embodiments, the light-transmitting body 102 may be made of a material that may be transparent or translucent to light or electromagnetic radiation having wavelength(s) in or within a range of 350 nm to 750 nm.

[00026] The light-transmitting body 102 of the light-transmission unit 101 of the optic device 100 may include a light-input surface 110 (e.g. a light-entry surface). The light-input surface 110 may be at an upper or top end of the light-transmitting body 102 (e.g. when the light-transmitting body 102 is in one of the potential usage orientations, e.g. substantially upright orientation as shown in FIG. 2A, FIG. 2B and FIG. 2C). The light-input surface 110 of the light-transmitting body 102 may be capable of or may be configured for a light (e.g. from an external light source, such as the Sun or an artificial light source) to enter the light-transmitting body 102. Accordingly, the light-input

surface 110 of the light-transmitting body 102 may allow light to penetrate into the light-transmitting body 102.

[00027] According to various embodiments, the light-input surface 110 may include or may be a planar surface (e.g. entirely or partially), for example, as shown in FIG. 2A and FIG. 2B. Herein, a “planar” surface may be defined as a flat (e.g. substantially flat) and/or level surface. Thus, the light-input surface 110 may include or may be a flat (e.g. substantially flat) surface capable of allowing light (e.g. travelling towards the light-input surface 110) to enter the light-transmitting body 102 via the light-input surface 110.

[00028] According to various other embodiments, the light-input surface 110 may include or may be a curved surface (e.g. entirely or partially). For example, according to various other embodiments, the light-input surface 110 may include or may be a convex-shaped surface, or a concave-shaped surface, or a saw-tooth surface, or a wavy surface etc. Said light-input surface 110 may include and may be a curved surface (e.g. entirely or partially) along any direction with respect to and/or along and/or on the reference plane 25. According to various embodiments, the light-input surface 110 may include or may be a symmetrical curved surface, for example, as shown in FIG. 2C. According to various other embodiments, the light-input surface 110 may include or may be an asymmetrical curved surface.

[00029] According to various embodiments, the light-input surface 110 may possess an anti-reflection property that may reduce or eliminate potential reflection of light (e.g. light rays) that is incident on the light-input surface 110. For example, the light-input surface 110 may include or may be configured with one or more anti-reflection layer(s). The anti-reflection layer(s) may include anti-reflection coating(s), and/or an array of anti-reflection surface topography. The anti-reflection surface topography may include surface nanotopographies or surface microstructures (e.g. moth-eye nanostructure arrays, etc.).

[00030] According to various embodiments, the light-transmitting body 102 of the light-transmission unit 101 of the optic device 100 may include a light-output surface 120. The light-output surface 120 may be on another side of the light-transmitting body 102, opposite (e.g. substantially opposite) the light-input surface 110 of the light-transmitting body 102. Accordingly, the light-output surface 120 and the light-input surface 110 may be facing in opposite (e.g. substantially opposite) directions or away

from each other. Accordingly, when the light-transmitting body 102 of the light-transmission unit 101 of the optic device 100 is in the potential usage orientation as shown in FIG. 2A, FIG. 2B and FIG. 2C, the light-input surface 110 may be at the upper or top end of the light-transmitting body 102 while the light-output surface 120 may be at a lower or bottom end of the light-transmitting body 102. The light-output surface 120 may be configured to enable or for at least a portion of the light (e.g. that entered the light-transmitting body 102 via the light-input surface 110) to exit from the light-transmitting body 102 via the light-output surface 120. In other words, at least a portion of the light that entered the light-transmitting body 102 via the light-input surface 110 may be transmitted through the light-transmitting body 102 to the light-output surface 120 to exit the light-transmitting body 102 via the light-output surface 120.

[00031] According to various embodiments, the light-transmitting body 102 of the light-transmission unit 101 of the optic device 100 may include (e.g. further include) a first planar side surface 130 extending between the light-input surface 110 and the light-output surface 120.

[00032] The first planar side surface 130 may be adjoining the light-input surface 110 at a first edge 131 (e.g. upper or top edge, when the light-transmitting body 102 is in the potential usage orientation, e.g. substantially upright orientation as shown in FIG. 2A, FIG. 2B and FIG. 2C) of the first planar side surface 130. Accordingly, the first edge 131 of the first planar side surface 130 may be a border of the first planar side surface 130 which meets the light-input surface 110. Hence, the light-input surface 110 may transit to the first planar side surface 130 across the first edge 131 of the first planar side surface 130. A second edge 132 (e.g. lower or bottom edge) of the first planar side surface 130 may be opposite the first edge 131 of the first planar side surface 130. Accordingly, the first edge 131 and the second edge 132 of the first planar side surface 130 may be two opposite edges of the first planar side surface 130. The light-output surface 120 may extend from the second edge 132 of the first planar side surface 130. Accordingly, the second edge 132 of the first planar side surface 130 may be a transition between the first planar side surface 130 and the light-output surface 120. Hence, the first planar side surface 130 may transit to the light-output surface 120 across the second edge 132 of the first planar side surface 130.

[00033] The light-transmitting body 102 of the light-transmission unit 101 of the optic device 100 may include a second planar side surface 140 that may be opposite to

and may be parallel with the first planar side surface 130. According to various embodiments, the light-transmitting body 102 may be of an elongated shape, and the first planar side surface 130 and the second planar side surface 140 may be two opposite and parallel longitudinal side surfaces of the elongated shape. The second planar side surface 140 may be adjoining the light-input surface 110 at a first edge 141 (e.g. upper or top edge) of the second planar side surface 140. Accordingly, the first edge 141 of the second planar side surface 140 may be a border of the second planar side surface 140 which meets the light-input surface 110. Hence, the light-input surface 110 may transit to the second planar side surface 140 across the first edge 141 of the second planar side surface 140. A second edge 142 (e.g. lower or bottom edge) of the second planar side surface 140 may be opposite the first edge 141 of the second planar side surface 140. Accordingly, the first edge 141 and the second edge 142 of the second planar side surface 140 may be two opposite edges of the second planar side surface 140.

[00034] According to various embodiments, the first edge 131 (e.g. upper or top edge) of the first planar side surface 130 and the first edge 141 (e.g. upper or top edge) of the second planar side surface 140 may be parallel to each other.

[00035] According to various embodiments, the first edge 131 of the first planar side surface 130 and the first edge 141 of the second planar side surface 140 may define a reference plane 25 (as shown in FIG. 2A to FIG. 2C). The reference plane 25 may be a planar (in other words, flat or substantially flat) reference plane 25, that may be bounded by (and/or adjoining and extending between) the first edge 131 of the first planar side surface 130 and the first edge 141 of the second planar side surface 140. Accordingly, the reference plane 25 may be extending directly between the first edge 131 of the first planar side surface 130 and the first edge 141 of the second planar side surface 140. According to various embodiments, the reference plane 25 may be horizontally-oriented (e.g. substantially horizontally-oriented), when the light-transmitting body 102 of the light-transmission unit 101 of the optic device 100 is in the potential usage orientation as shown in FIG. 2A, FIG. 2B, and FIG. 2C.

[00036] According to various embodiments, the first planar side surface 130 may form a non-zero acute internal angle, α , (i.e. greater than 0° and less than 90°) with the reference plane 25. Herein, an “internal angle” may be defined as an angle measured within the light-transmitting body 102. Accordingly, the non-zero acute internal angle,

α , between the first planar side surface 130 and the reference plane 25 may be an angle measured from the first planar side surface 130 to the reference plane 25, or vice versa (i.e. from the reference plane 25 to the first planar side surface 130), within the light-transmitting body 102.

[00037] As the second planar side surface 140 may be opposite and parallel to the first planar side surface 130, the second planar side surface 140 may accordingly form an obtuse internal angle, β , (i.e. greater than 90° and less than 180°) with the reference plane 25. A value of the obtuse internal angle, β , may be based on a value of the non-zero acute angle. That is, a summation of a value of the non-zero acute internal angle, α , (i.e. formed between the first planar side surface 130 and the reference plane 25) and a value of the obtuse internal angle, β , (i.e. formed between the second planar side surface 140 and the reference plane 25) may be equal to (e.g. substantially equal to) 180° .

[00038] As such, the reference plane 25 (i.e. planar reference plane 25), the first planar side surface 130, and the second planar side surface 140 may define a parallelepiped-shaped (or parallelepiped-like-shaped) region or portion of the light-transmitting body 102 of the light-transmission unit 101 of the optic device 100. Specifically, the light-transmitting body 102 may further include a third planar side surface 170 (for example, see FIG. 1) extending between the first planar side surface 130 and the second planar side surface 140 as well as extending between the light-input surface 110 and the light-output surface 120. Further, the light-transmitting body 102 of the light-transmission unit 101 of the optic device 100 may include a fourth planar side surface 180 (for example, see FIG. 1) opposite to and parallel with the third planar side surface 170. That is, the fourth planar side surface 180 may be extending between the first planar side surface 130 and the second planar side surface 140 as well as extending between the light-input surface 110 and the light-output surface 120. Each of the third planar side surface 170 and the fourth planar side surface 180 may form an internal angle that is perpendicular or substantially perpendicular (i.e. 90° or substantially 90°) with the reference plane 25. The parallelepiped-shaped (or parallelepiped-like-shaped) region or portion of the light-transmitting body 102 may be defined by the four planar side surfaces (i.e. the first planar side surface 130, the second planar side surface 140, the third planar side surface 170, and the fourth planar side

surface 180) as well as the planar reference plane 25. The parallelepiped-shaped (or parallelepiped-like-shaped) region or portion of the light-transmitting body 102 may be between the light-input surface 110 and the light-output surface 120.

[00039] According to various embodiments, at least a region of the light-output surface 120 may be offset from at least a region of the light-input surface 110 in an offset direction 26 corresponding to a direction extending from the first planar side surface 130 to the second planar side surface 140 in a manner substantially parallel with the reference plane 25. Accordingly, the light-input surface 110 and the light-output surface 120 may be partially overlapping, or may not be overlapping at all, with respect to each other, when viewed from a direction extending perpendicularly (e.g. substantially perpendicularly) to the reference plane 25, such as the view shown in FIG. 1. Referring to FIG.1, the light-input surface 110 is not superimposed over the light-output surface 120. Rather, the light-input surface 110 and the light-output surface 120 are offset or shifted relative to each other such that the light-input surface 110 partially overlaps the light-output surface 120 when viewed from the direction extending perpendicularly to the reference plane 25 (i.e. from the view shown in FIG. 1).

[00040] According to various embodiments, the light-output surface 120 may be or may include a curved surface 160 extending from (e.g. starting or beginning from) the second edge 132 of the first planar side surface 130. According to various embodiments, the light-output surface 120 may curve away from the first planar side surface 130 in the offset direction 26 or generally along a path curving towards a direction corresponding to the offset direction 26. In other words, according to various embodiments, the curved surface 160 of the light-output surface 120 may curve away from the first planar side surface 130 and/or away from the light-input surface 110. According to various embodiments, the curved surface 160 of the light-output surface 120 may form or may be the entire light-output surface 120 (as shown in FIG. 2A and FIG. 2C). In other words, according to various embodiments, the curved surface 160 of the light-output surface 120 may extend from the second edge 132 of the first planar side surface 130 to the second edge 142 of the second planar side surface 140 (elaborated later with reference to FIG. 2A). Further, according to various embodiments, the curved surface 160 of the light-output surface 120 (or a curvature of the curved surface 160) may include or have a gradient or slope (e.g. with respect to the first planar side surface 130) that increases (e.g. gradually and/or progressively

increases, in other words, becomes steeper) from the second edge 132 of the first planar side surface 130 towards the second edge 142 of the second planar side surface 140. According to various embodiments, the curved surface 160 of the light-output surface 120 may be an asymmetric curved surface. According to various embodiments, the curved surface 160 of the light-output surface 120 and the second planar side surface 140 may form a corner portion 290 (shown in FIG. 2A and FIG. 2C) along the second edge 142 of the second planar side surface 140. Accordingly, the curved surface 160 of the light-output surface 120 and the second planar side surface 140 may meet along the second edge 142 of the second planar side surface 140 in a manner to form the corner portion 290.

[00041] According to various other embodiments, the curved surface 160 may be a segment (in other words, a portion or a fraction) of the light-output surface 120, such that remaining segment(s) (in other words, remaining portion(s) or fraction(s)) of the light-output surface 120 may include at least an auxiliary planar (e.g. flat or substantially flat) surface 223B (as shown in FIG. 2B). In other words, according to various other embodiments, the light-output surface 120 may further (e.g. in addition to the curved surface 160) include the auxiliary planar surface 223B. According to various other embodiments, the auxiliary planar surface 223B of the light-output surface 120 may extend from a distal edge 224B of the curved surface 160 of the light-output surface 120. The distal edge 224B of the curved surface 160 may be an edge of the curved surface 160 opposite the second edge 132 of the first planar side surface 130 or furthest away from the second edge 132 of the first planar side surface 130. According to various other embodiments, the auxiliary planar surface 223B may be extending between the curved surface 160 and the second edge 142 of the second planar side surface 140. As shown in FIG. 2B, the light-output surface 120 may include the curved surface 160 and the auxiliary planar surface 223B.

[00042] In operation, a light (e.g. Sunlight) may enter the light-input surface 110 of the light-transmitting body 102 of the light-transmission unit 101 of the optic device 100 with an entry angle in or within a range from 0° to 90° (in other words, inclusive of 0° and inclusive of 90°) measured from a normal 27 of the reference plane 25. The normal 27 may be a line extending perpendicularly from the reference plane 25, which is defined and bounded by the first edge 131 of the first planar side surface 130 and the first edge 141 of the second planar side surface 140, in an outward direction with respect

to the light-input surface 110. In other words, the normal 27 is extending in a direction which the light-input surface 110 is facing. Accordingly, the light may be entering the light input surface 110 of the light-transmitting body 102 at any angle corresponding to a range of angles, θ , from the normal 27 to a line extending perpendicularly from the first edge 131 of the first planar side surface 130 to the normal 27 of the reference plane 25. According to various embodiments, the light may be transmitted across and/or redirected by the light-transmitting body 102 to exit the light-transmitting body 102 from the light-output surface 120 of the light-transmitting body 102 at an exit angle in or within a range of 180° to 270° (in other words, inclusive of 180° and inclusive of 270°) measured from the normal 27 of the reference plane 25. Accordingly, the light may be exiting the light-output surface 120 of the light-transmitting body 102 at an angle corresponding to a range of angles, λ , from an inverse of the normal 27 to a line extending perpendicularly from the first edge 141 of the second planar side surface 140 to the inverse normal 27 of the reference plane 25. In other words, the light-transmitting body 102 of the light-transmission unit 101 of the optic device 100, according to various embodiments, may be capable of transmitting and/or redirecting a light entering the light-transmitting body 102, via the light-input surface 110, with the entry angle in or within the range of 0° to 90° measured from the normal 27 of the reference plane 25, to exit from the light-transmitting body 102, via the light-output surface 120, at the exit angle in or within a range of 180° to 270° measured from the normal 27 of the reference plane 25.

[00043] In an application or a mode of use of the optic device 100, according to various embodiments, the light-transmission unit 101 (or the light-transmitting body 102 of the light-transmission unit 101) of the optic device 100 may be positioned at and/or secured to (e.g. immediately adjacent to) a side of a cultivation column 13 (for example, see FIG. 4A), with the light-input surface 110 of the body 102 of the light-transmission unit 101 facing a direction corresponding to an upward direction along a column axis 19 of the cultivation column 13, and with a longitudinal axis of the light-transmitting body 102 (e.g. which may be parallel to the first planar side surface 130 and the second planar side surface 140) extending along a lateral direction being transverse to the column axis. Accordingly, at least a portion of light that enters the light-transmitting body 102 via the light-input surface 110 may be transmitted across the light-transmitting body 102 and redirected by the light-transmitting body 102 to exit

from the light-output surface 120 of the light-transmitting body 102, to be distributed (e.g. with uniform or substantially uniform irradiation across the distribution area) to the lower and/or inner shaded region(s)/tier(s) of the cultivation column 13.

[00044] According to various embodiments, the optic device 100 may include an attachment member 77 (for example, see FIG. 7A or FIG. 7B) disposed at a side of the light-transmission unit 101. The attachment member 77 may be configured to or may be for securing the optic device 100 to an external structure (e.g. a cultivation column, a multi-tiered rack, a wall, a platform etc.). For example, the attachment member 77 may include any one or a combination selected from a clamp, a bracket, a nut and bolt assembly, an adhesive (e.g. glue), a clip, a buckle, an adhesive, a nut and bolt assembly, a cable, or any other suitable attachment member for securing the optic device 100 to the external structure.

[00045] According to various embodiments, the light-transmitting body 102 may be a rigid body 102. In other words, according to various embodiments, the body 102 may be inflexible. That is, according to various embodiments, the rigid light-transmitting body 102 may be made of high stiffness/rigidity as well as light permeable (in other words, transparent or translucent) material, for example, glass, polymer, ceramic(s) (e.g. light transmitting ceramic(s)), etc. Accordingly, according to various embodiments, the light-transmitting body 102 may be a solid piece of rigid light permeable material.

[00046] Referring to FIG. 2A, according to various embodiments, the light-transmission unit 101 of the optic device 100 may include the first variant 102A of the light-transmitting body 102 (or the first variant body 102A).

[00047] The first variant body 102A may include the light-input surface 110 for receiving a light into the first variant body 102A. As shown, according to various embodiments, the light-input surface 110 of the first variant body 102A may be a planar (in other words, flat or substantially flat) light-input surface 110.

[00048] Further, the first variant body 102A may include the light-output surface 120 for at least a portion of the light (i.e. that entered the first variant body 102A via the light-input surface 110) to exit the first variant body 102A.

[00049] Further, the first variant body 102A may include the first planar side surface 130 extending between the light-input surface 110 and the light-output surface 120. As shown, the first planar side surface 130 of the first variant body 102A may adjoin the

light-input surface 110 at the first edge 131 (e.g. an upper or top edge, when the first variant body 102A is in the potential usage orientation, e.g. substantially upright orientation as shown in FIG. 2A) of the first planar side surface 130.

[00050] Further, the first variant body 102A may include (e.g. further include) the second planar side surface 140 opposite to and parallel with the first planar side surface 130. As shown, the second planar side surface 140 of the first variant body 102A may adjoin the light-input surface 110 at the first edge 141 of the second planar side surface 140 of the first variant body 102A.

[00051] As shown, the first edge 131 of the first planar side surface 130 and the first edge 141 of the second planar side surface 140 of the first variant body 102A may be parallel (e.g. substantially parallel) to each other. The parallel and opposite first edge 131 of the first planar side surface 130 and the first edge 141 of the second planar side surface 140 may define the reference plane 25. The reference plane 25 may be a planar (in other words, flat or substantially flat) reference plane 25, that may adjoin and/or extend between the first edge 131 of the first planar side surface 130 and the first edge 141 of the second planar side surface 140 of the first variant body 102A.

[00052] The reference plane 25 (e.g. planar reference plane 25) of the first variant body 102A may be coincident (in other words, lie on a same plane) with the light-input surface 110 (e.g. planar light-input surface) of the first variant body 102A. In other words, the planar light-input surface 110 of the first variant body 102A may coincide with the reference plane 25 of the first variant body 102A.

[00053] As shown, the first planar side surface 130 of the first variant body 102A may form a non-zero acute internal angle, α , (i.e. greater than 0° and less than 90°) with the planar reference plane 25 (or with the coincident planar light-input surface 110) of the first variant body 102A. For example, the non-zero acute internal angle, α , between the first planar side surface 130 and the reference plane 25 (or the coincident planar light-input surface 110) may be of a value in or within a range of 40° to 80° (e.g. 60°).

[00054] Conversely, the second planar side surface 140 (being opposite and parallel to the first planar side surface 130) of the first variant body 102A may form an obtuse internal angle, β , with the planar reference plane 25 (or the coincident planar light-input surface 110) of the first variant body 102A equivalent to 180° minus the non-zero

acute internal angle, α . For example, when the non-zero acute internal angle, α , is (or is approximately) 60° , the obtuse internal angle, β , may be (or may be approximately) 120° . That is, a summation of a value of the non-zero acute internal angle, α , and a value of the obtuse internal angle, β , may be equal to (e.g. substantially equal to) 180° .

[00055] As shown, the planar light-input surface 110, the first planar side surface 130, and the second planar side surface 140 of the first variant body 102A may define a parallelepiped-shaped (or parallelepiped-like-shaped) region or portion of the first variant body 102A. In particular, the first variant body 102A may further include the third planar side surface 170 extending between the first planar side surface 130 and the second planar side surface 140 as well as extending between the light-input surface 110 and the light-output surface 120. Further, the first variant body 102A may include the fourth planar side surface 180 opposite to and parallel with the third planar side surface 170. That is, the fourth planar side surface 180 may be extending between the first planar side surface 130 and the second planar side surface 140 as well as extending between the light-input surface 110 and the light-output surface 120. Each of the third planar side surface 170 and the fourth planar side surface 180 may form an internal angle that is perpendicular or substantially perpendicular (i.e. 90° or substantially 90°) with the planar light-input surface 110 and/or the reference plane 25 (i.e. which may be coincident with the planar light-input surface 110) of the first variant body 102A. The parallelepiped-shaped (or parallelepiped-like-shaped) region or portion of the first variant body 102A may be defined by the four planar side surfaces (i.e. the first planar side surface 130, the second planar side surface 140, the third planar side surface 170, and the fourth planar side surface, 180) as well as the planar light-input surface 110 of the first variant body 102A.

[00056] As shown, at least a region (or portion) of the light-output surface 120 (e.g. extending from or adjoining the second edge 142 of the second planar side surface 140) of the first variant body 102A may be offset with respect to at least a region (or portion) of the light-input surface 110 (e.g. extending from or adjoining the first edge 131 of the first planar side surface 130) in the offset direction 26 corresponding to the direction extending from the first planar side surface 130 to the second planar side surface 140 in a manner substantially parallel with the reference plane 25 and/or the light-input surface 110 of the first variant body 102A.

[00057] According to various embodiments, the light-output surface 120 of the first variant body 102A may include the curved surface 160 that adjoins and/or extends from the second edge 132 of the first planar side surface 130 and that may curve away from the first planar side surface 130 in the offset direction 26, or generally along the path curving towards a direction corresponding to the offset direction 26. In particular, as shown, a first portion 221A (e.g. a first segment) of the curved surface 160 of the light-output surface 120 may, adjoining and/or extending and/or starting from the second edge 132 of the first planar side surface 130, curve away from the first planar side surface 130 and/or curve away from the light-input surface 110 of the first variant body 102A. Accordingly, a gradient of the first portion 221A of the curved surface 160 of the light-output surface 220A of the first variant body 202A may start from a gradient parallel to the first planar side surface 130 of the first variant body 102A and gradually change until the gradient is parallel to the offset direction 26. Subsequently, a second portion 222A (e.g. a second segment) of the curved surface 160 of the light-output surface 120 of the first variant body 102A may continue to curve away from the first planar side surface 130 of the first variant body 102A and curve upwards towards the second planar side surface 140 of the first variant body 102A. Accordingly, a gradient of the second portion 222A of the curved surface 160 of the light-output surface 120 of the first variant body 102A may start from being parallel to the offset direction 26 and increases (e.g. gradually and/or progressively increase) until the second portion 222A of the curved surface 160 of the light-output surface 120 of the first variant body 102A joins the second planar side surface 140 at the second edge 142 of the second planar side surface 140 of the first variant body 102A. Hence, the curved surface 160 of the light-output surface 220A of the first variant body 202A may have the first portion 221A that curves away and downwards (e.g. when the first variant body 102A is in the potential usage orientation as shown in FIG. 2A) with respect to the first planar side surface 130, and the second portion 222A that curves away and upwards (e.g. towards or slightly towards the light-input surface 110, when the first variant body 102A is in the potential usage orientation as shown in FIG. 2A) with respect to the first planar side surface 130.

[00058] As shown, according to various embodiments, in the first variant body 102A, the second planar side surface 140 may be larger (e.g. taller) than the first planar side surface 130. That is, a direct distance measured between the first and second edges 141

and 142 of the second planar side surface 140 may be larger than a direct distance measured between the first and second edges 131 and 132 of the first planar side surface 130. The direct distance may be defined as a shortest distance measured perpendicularly with respect to the first and second edges 141 and 142, or to the first and second edges 131 and 132, respectively.

[00059] According to various embodiments, the first variant body 102A may be of a fin-like shaped (e.g. a fin-shaped lenticular prism). The cross-section of the first variant body 102A may resemble a trapezoid with two straight parallel sides (e.g. first planar side surface 130 and second planar side surface 140), a straight light entry profile (e.g. light-input surface 110) or a curved light entry profile (e.g. see FIG. 2C), and a curved (e.g. asymmetrically curved) light exiting profile (e.g. light-output surface 120). One of the straight sides (e.g. the second planar side surface 140) may be angled (e.g. forming an internal angle, β) with respect to the light entry face (e.g. light-input surface 110) with an angle (e.g. obtuse angle) between 90° to 180° , or between or within a range of 100° to 140° . Accordingly, the other one of the straight sides (e.g. the first planar side surface 130) may be angled (e.g. forming an internal angle, α) with respect to the light entry face (e.g. light-input surface 110) with an angle (e.g. acute angle) between 0° to 90° , or between or within a range of 40° to 80° .

[00060] According to various embodiments, when a plurality of the first variant bodies 102A are joined side-by-side or end-to-end (described in detail later with respect to FIG. 3A), each first variant body 102A may form an “over-hanging portion” (e.g. the corner portion 290 and/or the second portion 222A of the curved surface 160) which may extend over an adjacent (e.g. immediately adjacent) first variant body 102A due to the angling (e.g. offset between the light-input surface 110 and the light-output surface 120) of the first variant body 102A .

[00061] According to various embodiments, one or more or all cross-sectional dimension(s) of the first variant body 102A may range between 1 micron to 50 cm. As the dimension(s) and/or format and/or shape of a cultivation column (to which the first variant body 102A may be attached) may dictate or determine an optimum light redirection angle required (e.g. for plant cultivation on lower cultivation tier(s) of the cultivation column), dimension(s) of the first variant body 102A, including curvature of its light exiting face (e.g. light-output surface 120), may be customized or tailored

based on the dimension(s) and/or format and/or shape of the cultivation column, to optimize a redirection efficiency.

[00062] According to various embodiments, the light-output surface 120 of the first variant body 102A may include an asymmetrical curvature or shape, which may enable the light-output surface 120 of the first variant body 102A to bend or spread an exiting light to a target area, with improved uniformity of irradiance. In particular, the asymmetrical curvature of the light-output surface 120 of the first variant body 102A may help in spreading light over a target area. The “over-hanging portion” (e.g. the corner portion 290 and/or the second portion 222A of the curved surface 160) – which may be an extension or protrusion of the light transmission unit 101 – may improve (in other words, enhance) uniformity of the irradiance. Accordingly, a combination of the light-output surface 120 and the “over-hanging portion” (e.g. the corner portion 290 and/or the second portion 222A of the curved surface 160) may provide targeted delivery of Sunlight to plant beds (e.g. lower cultivation tiers) yet maintain a certain degree of uniformity in the PAR irradiation across the target area.

[00063] Referring to FIG. 2B, according to various embodiments, the light-transmission unit 101 of the optic device 100 may include the second variant 102B of the light-transmitting body 102 (or the second variant body 102B).

[00064] Similar to the first variant body 102A of FIG. 2A, the second variant body 102B may include the light-input surface 110, the first planar side surface 130, and the second planar side surface 140.

[00065] Similar to the first variant body 102A of FIG. 2A, the second variant body 102B may include the light-output surface 120 having the curved surface 160. However, the second variant body 102B may differ from the first variant body 102A in that a light-output surface 120 of the second variant body 102B may include the auxiliary planar surface 223B (i.e. instead of the second portion 222A shown in FIG. 2A). The auxiliary planar surface 223B may be adjoining a second edge 142 of the second planar side surface 140 of the second variant body 102B. Specifically, the auxiliary planar surface 223B may be extending between the curved surface 160 of the light-output surface 120 and the second planar side surface 140 of the second variant body 102B.

[00066] Referring to FIG. 2C, according to various embodiments, the light-transmission unit 101 of the optic device 100 may include the third variant 102C of the light-transmitting body 102 (or the third variant body 102C).

[00067] Similar to the first variant body 102A of FIG. 2A, the third variant body 102C may include the first planar side surface 130, the second planar side surface 140, and the light-output surface 120.

[00068] The third variant body 102C may differ from the first variant body 102A in that a light-input surface 110 of the third variant body 102C may include or may be a curved surface 210C (in other words, having a curved light entry profile). As shown, but not limited thereto, the curved surface 210C of the light-input surface 110 may be a convex-shaped surface.

[00069] While the light-transmitting body 102 is illustrated by the first variant body 102A in FIG. 2A, the second variant body 102B in FIG. 2B, the third variant body 102C in FIG. 2C, it is understood that further variants of the light-transmitting body 102 or modification may be made, for example, by varying or combining features from the different variants to form new variants. For examples, other variants may include convex or concave light-input surface 110, or combination of curved light-input surface 110 and light-output surface 120 with the auxiliary planar surface 223B etc. Accordingly, it is understood that the variants of the light-transmitting body 102 as shown in FIG. 2A, FIG. 2B and FIG. 2C are non-exhaustive and, hence, the light-transmitting body 102 is not limited to only the first variant body 102A in FIG. 2A, the second variant body 102B in FIG. 2B, the third variant body 102C in FIG. 2C.

[00070] FIG. 3A shows a schematic side view of a light-transmission unit 301A of an optic device 300A. As shown, the light-transmission unit 301A may include a plurality of first variant bodies 102A to form a single unitary panel structure 350A (e.g. a panel), according to various embodiments. While the light-transmission unit 301A (e.g. the panel) in FIG. 3A is illustrated to be formed by the first variant body 102A, it is understood that the light-transmission unit 301A may be formed by any variant of the light-transmitting body 102 and is not limited thereto. Accordingly, it is understood the in the following, the first variant body 102A may be interchangeable with any variant of the light-transmitting body 102. For example, the light-transmission unit 301A (e.g. the panel), according to various embodiments, may include a plurality of the second variant bodies 102B (as described with reference to FIG. 2B), or a plurality of

the third variant bodies 102C (as described with reference to FIG. 2C), or a combination of at least two or more different types of light-transmitting bodies 102 (e.g. combination of the first variant body 102A and/or the second variant body 102B and/or the third variant body 102C). According to various other embodiments, the light-transmission unit 301A (e.g. the panel) may include different types (e.g. with respect to shape, form, dimension(s), etc.) of light-transmitting bodies 102. For example, according to various other embodiments, the light-transmission unit 301A (e.g. the panel) may include light-transmitting bodies 102 having different shapes (e.g. having varied curvatures or curved cross-sectional profiles) of light-input surfaces 110 and/or of light-output surfaces 120. For example, according to various other embodiments, the curve surfaces 160 of light-output surfaces 120 of the plurality of light-transmitting bodies 102 (e.g. of at least two or more or all) forming the panel may have different curvatures from each other (for example, as shown in FIG. 7C and FIG. 7D). As such, according to various other embodiments, different portions or locations along a panel may include different types of light-transmitting bodies 102 (e.g. for “tailored” or “customized” targeting of redirected light from each light-transmitting body 102 of light-transmission unit 301A (e.g. the panel) to distribution area(s), e.g. within a cultivation column or multi-tiered rack, desired to be illuminated / to receive light).

[00071] According to various embodiments, a plurality (e.g. two, three or more) of the first variant bodies 102A may be coupled or joined or connected together in a side-to-side arrangement or lined abreast. In other words, the plurality of the first variant 102A of the light-transmitting bodies 120 may be assembled together, alongside each other, to form the single unitary panel structure 350A (e.g. a light redirection panel or a panel) (herein may be referred to as a “panel”). Accordingly, a panel may be the light-transmission unit 301A. As such, hereinafter, the terms “panel” and “light-transmission unit” may be used interchangeably. As an example, and for ease of illustration, FIG. 3A shows the panel 350A including ‘three’ first variant bodies 102A. Nevertheless, it is understood that the panel 350A according to various embodiments is not limited to being formed of only three first variant bodies 102A, and may include any other plural number of the first variant bodies 102A (e.g. four or five or more). Each first variant body 102A of the panel 350A may be referred to as a “subunit”.

[00072] According to various embodiments, the optic device 300A may include at least one panel 350A.

[00073] With reference to FIG. 3A, according to various embodiments, within the panel 350A, each pair of adjacent (e.g. immediately adjacent) or neighboring (e.g. immediately neighboring) first variant bodies 102A may be in contact (e.g. physical contact) or abutting each other via a first planar side surface 130 of a first (or one) of the pair (or each pair) of adjacent or neighboring first variant bodies 102A and a second planar side surface 140 of a second (or another) of the pair (or each pair) of adjacent or neighboring first variant bodies 102A. In other words, according to various embodiments, a first light-transmitting body (e.g. a first variant body 102A) and a second (or further) light-transmitting body (e.g. another first variant body 102A) may be coupled and/or engaged with each other to form the panel 350A (or a portion of the panel 350A), in a manner such that a first planar side surface 130 of the first light-transmitting body and a second planar side surface 140 of the second (or further) light-transmitting body may be contacting or abutting each other.

[00074] As shown in FIG. 3A, according to various embodiments, within the panel 350A – specifically within each pair of adjacent or neighboring first variant bodies 102A – the corner portion 290 of ‘one’ of the plurality of first variant bodies 102A may extend over the first portion 221A of the curved surface 160 of the light-output surface 120 of an ‘adjacent or neighbouring’ (e.g. another) first variant body 102A. The corner portion 290 (i.e. of the said ‘one’ of the plurality of first variant bodies 102A) may be a corner which the second portion 222A of the curved surface 160 of the light-output surface 120 (i.e. of the said ‘one’ of the plurality of first variant bodies 102A) joins the second edge 142 of the second planar side surface 140 (e.g. of the said ‘one’ of the plurality of first variant bodies 102A).

[00075] Further, as shown, according to various embodiments, (at least some or all of) the reference planes 25 (or the planar light-input surface 110) of the first variant bodies 102A of the panel 350A may be aligned. In other words, according to various embodiments, the reference planes 25 (or the planar light-input surface 110) of the first variant bodies 102A within the panel 350A may be parallel to each other and/or may all lie on a same plane.

[00076] According to various other embodiments (not shown), the reference plane(s) 25 (or the planar light-input surface 110) of two or more bodies 102A of the panel 350A may lie on different planes (or different heights, e.g. with respect to each other, or with respect to a central horizontal plane of the panel).

[00077] According to various other embodiments, the reference planes 25 (or the planar light-input surface 110) of two or more bodies of a panel may lie at different orientations (e.g. angles) with respect to each other.

[00078] According to various embodiments, each subunit (e.g. each first variant body 102A) of the panel 350A may be fabricated using Computer numerical control (CNC) machining, three-dimensional (3D) printing, injection molding, casting, extrusion, imprinting, hot embossing, soft lithography techniques, or any other suitable fabrication process. The fabricated subunits (e.g. each first variant body 102A) may then be held in place relative to each other by adhesive, glue, mechanical fixture, etc. to form the panel 350A.

[00079] According to various other embodiments (not shown), each panel (not shown) may be a monolithic (in other words, single and integral) piece which may be fabricated (e.g. as a single unit) using CNC machining, 3D printing, injection molding, casting, extrusion, imprinting, soft lithography techniques, or any other suitable fabrication process (e.g. while preserving the surface profile of the lenticules or subunits or light-transmitting bodies).

[00080] The panel (e.g. a light redirection panel), or each light-transmitting body of the panel, according to various embodiments, may be configured or used to redirect and/or distribute an incoming light (e.g. from the Sun or an artificial light source) to region(s) (e.g. initially shaded region(s)) within a cultivation column (e.g. on one or more initially shaded upward-facing surface(s) of lower tier(s) or platform(s) of the cultivation column).

[00081] FIG. 3B is an image depicting simulation of light paths 12 of Sunlight received and redirected by a panel 350B (or light transmission unit) of an optic device 300B, according to various embodiments.

[00082] The panel 350B of FIG. 3B may include a plurality of light-transmitting bodies 102. As shown, one or more light-transmitting body/bodies 102 of the panel 350B of FIG. 3B may be similar or identical to the first variant bodies 102A of FIG. 2A. Further, at least one light-transmitting body 102 of the panel 350B may be shaped and/or oriented (e.g. angled) differently from the remaining light-transmitting bodies 102 of the panel 350B.

[00083] As shown in FIG. 3B, at least a portion of light received by the panel 350B (or the light-transmitting bodies 102 of the panel 350B) may be redirected by the panel

350B (or light-transmitting bodies 102 of the panel 350B) in a manner suitable for illuminating a lower cultivation tier of a cultivation column, when the panel 350B is attached to a side of a higher cultivation tier (e.g. overhead the lower tier) within the cultivation column. According to various embodiments, redirection of the light may be due to refraction or internal reflection or a combination of refraction and internal reflection within one light-transmitting body 102 or across the light-transmitting bodies of the panel 350B.

[00084] For example, as shown in FIG. 3B (and with reference to FIG. 2A), at least a portion of the light travelling along the light paths 12a entering through a light-input surface (e.g. corresponding to the light-input surface 110 of FIG. 2A) of each or any one light-transmitting body 102 of the panel 350B with an entry angle in or within a range from 0° to 90° from a normal (e.g. corresponding to the normal 27 of FIG. 2A) may be altered or changed by way of refraction. Within each light-transmitting body 102, at least a portion of the refracted light travelling along light paths 12b may be projected on a first planar side surface and/or a curved surface (e.g. corresponding to the first planar side surface 130 and/or the curved surface 160 or the first segment 221A of the curved surface 160 of FIG. 2A) of said light-transmitting body 102. At least a portion of the refracted light travelling along light paths 12b may be internally reflected by the said first planar side surface and/or the said curved surface to light path 12c and exit said light-transmitting body 102 through a second planar side surface (e.g. corresponding to the second planar side surface 140 of FIG. 2A) into the adjacent light-transmitting body which may then be internally reflected again one or more times within the panel 350B before exiting the panel 350B. Further, at least a portion of the refracted light travelling along light paths 12b may exit said light-transmitting body 102 through a curved surface (e.g. corresponding to the curved surface 160 or the second segment 222A of the curved surface 160 of FIG. 2A) and/or a second planar side surface (e.g. corresponding to lower segment of the second planar side surface 140 of FIG. 2A) of the light-transmitting body 102 of the panel 350B so as to travel along light path 12d out of the light-transmitting bodies 102 for illuminating a lower cultivation tier . Further, the light exiting the panel 350B may be altered through said surface(s) by way of refraction. Accordingly, the light exiting the panel 350B may be altered in such a way as to be directed onto a lower cultivation tier within the cultivation column (e.g.

when the panel 350B is installed onto a side/edge of a higher cultivation tier of the cultivation column).

[00085] FIG. 4A is a perspective view of a cultivation system 460 including a cultivation column 13 with two cultivation tiers 13A, 13B (e.g. tiers or platforms, plant beds etc.) and at least one panel 450A (or light transmission unit) mounted to at least one side of a topmost cultivation tier 13A of the cultivation column 13, according to various embodiments. FIG. 4B is an isolated perspective view of one panel 450A of FIG. 4A and an upward-facing surface 14B of a bottom cultivation tier 13B of the cultivation column 13 of FIG. 4A, according to various embodiments. FIG. 4C is a schematic side view of one panel 450A of FIG. 4A illustrating possible dimensions (in mm) of the panel 450A, according to various embodiments.

[00086] With reference to FIG. 4A to FIG. 4C, as an example, the panel 450A may include at least one (e.g. five) first variant bodies 102A. For ease of illustration, embodiments may be described with reference to the panel 450A as having five first variant bodies 102A (e.g. five subunits). Nevertheless, it is understood that the panel 450A is not limited to having five first variant bodies 102A, and may include any other plural number and/or type of light-transmitting body/bodies, according to various embodiments.

[00087] According to various embodiments, the optic device 400A may include at least one panel 450A.

[00088] With reference to FIG. 4C, the panel 450A may have a width of 80 mm. Accordingly, each first variant bodies 102A of the panel 450A may have a width (i.e. measured from a first planar side surface 130, e.g. a first edge 131 of the first planar side surface 130, to a second planar side surface 140, e.g. a first edge 141 of the second planar side surface 140) of 16 mm.

[00089] Referring back to FIG. 4A, according to various embodiments, the cultivation system 460 may be provided.

[00090] According to various embodiments, the cultivation system 460 may include at least one (e.g. one or more) cultivation column(s) 13 (e.g. multi-tiered rack).

[00091] According to various embodiments, each cultivation system 460 may include two or more cultivation tiers 13A, 13B arranged (e.g. one over another, or stacked) along a column axis 19. For ease of illustration, FIG. 4A shows the cultivation column 13 as having ‘two’ cultivation tiers 13A, 13B. Nevertheless, it is understood that the

cultivation column 13 is not limiting to having only ‘two’ cultivation tiers, and may include any other plural number of cultivation tiers. Herein, the terms “cultivation tier”, “tier”, and “platform” may be used interchangeably.

[00092] According to various embodiments, each cultivation system 460 may further include at least one optic device (e.g. the optic device 100, the optic device 300A, 300B and/or 400A, etc.).

[00093] As shown, one or more panel(s) (e.g. panels 450A of the optic device 400A) may be installed or mounted or secured to any one or more or all side(s) of one or more cultivation tier(s) (e.g. the upper cultivation tier 13A or topmost tier) of the cultivation column 13 (e.g. a two-tiered cultivation column), for instance, along lower edge(s) of the side(s) of the corresponding cultivation tier(s). For ease of illustration, the cultivation column 13A may be described as a two-tiered cultivation column. Nevertheless, it is understood that embodiments described with reference to the cultivation column 13A having two cultivation tiers is not limited thereto and, thus, may be extended or applicable to other types of cultivation columns, for example, a three-tiered cultivation column or multi-tiered rack (as shown in FIG. 4E), or a vertical-walled cultivation column or cultivation rack or grow wall (as shown in FIG. 4F), etc.

[00094] According to various embodiments, each panel 450A (or each first variant body 102A of the panel 450A, or the optic device 400A according to various embodiments) may include the attachment member 77 (for example, as shown in FIG. 7A or FIG. 7B) configured to or for attaching or mounting or securing the panel 450A (or the first variant body 102A) to a side and/or an edge (e.g. lower edge of the side) of upper cultivation tier 13A of the cultivation column 13, such that the panel 450A (or each first variant body 102A) may be immovably (e.g. permanently, or detachably) fixed in position at an angle and/or an orientation (e.g. desired angle and/or orientation) with respect to the cultivation column 13. For example, the attachment member 77 may include, any one or a combination selected from a clamp, a bracket, a nut and bolt assembly, an adhesive (e.g. glue), a clip, a buckle, an adhesive, a nut and bolt assembly, a cable, or any other suitable attachment member for attaching or mounting or securing the panel 450A (or each first variant body 102A) to the cultivation column 13.

[00095] According to various other embodiments, the attachment member may include an actuator (e.g. mechanical actuator) configured to or for moving the panel 450A (or each first variant body 102A) between two or more different positions and/or

orientations with respect to the cultivation column 13. The actuator, according to various other embodiments, may be configured to move the panel 450A (or each first variant body 102A) based on or depending on a position of the Sun and/or based on a time of a day, in a manner as to maximize an amount of light (e.g. Sunlight) being received and redirected by the panel 450A (or each first variant body 102A) to one or more lower and/or inner region(s) of tier(s) or platform(s) (e.g. of cultivation tier 13B) of the cultivation column 13 (e.g. which may otherwise be shaded by the upper cultivation tier 13A from direct Sunlight). According to various other embodiments, the actuator may further be configured to orientate or change an orientation of the panel 450A (or each first variant body 102A) such that the panel 450A (or each first variant body 102A) may be orientated parallel (e.g. substantially parallel) with respect to a vertical axis (e.g. column axis 19) of the cultivation column 13. The changing of orientation of the panel 450A (or each body 202A) by the actuator, according to various other embodiments, may be configured to take place, for example, during periods of low to moderate solar elevation to minimize obstruction of incoming Sunlight to lower and/or inner region(s) of the cultivation column 13. The actuator, according to various other embodiments, may consequently redeploy the panel 450A (e.g. to a usage orientation of the panel 450A for maximizing an amount of light that can be received by light-input surface(s) of the panel 450A).

[00096] According to various embodiments, the actuator (e.g. a mechanical actuator) may be configured to move the panel 450A automatically via a control system. According to various other embodiments, the actuator may be manually operated to move the panel 450A.

[00097] With reference to FIG. 4A, according to various embodiments, each panel 450A (or each first variant body 102A of the panel 450A) of the optic device 400A may be secured to a side and/or an edge (e.g. of an upper tier or platform 13A) of the cultivation column 13 in a manner such that light-input surface 110 of each first variant body 102A of the panel 450A may be facing a same or similar (in other words, almost a same) direction as an upward-facing surface (e.g. surface 14A) of the cultivation tier or platform (e.g. upper cultivation tier 13A) of the cultivation column 13 that the panel 450A (or each first variant body 102A) may be secured to.

[00098] Specifically, the optic device 400A may be coupled to a side of the cultivation column 13 in a manner so as to form an overhang protruding from the side

of the cultivation column 13 (e.g. side of the upper cultivation tier 13A) with the light-input surface 110 of the first variant body 102A (e.g. all of the first variant bodies 102A) of the panel 450A (or light-transmission unit 101) of the optic device 400A directed upwards with respect to the column axis 19 of the cultivation column 13 and the light-output surface 120 of the first variant body 102A of the panel 450A (or light-transmission unit 101) of the optic device 400A directed downwards with respect to the column axis 19 of the cultivation column 13, such that the panel 450A (or light-transmission unit 101) of the optic device 400A may be capable of directing the light incident on the light-input surface 110 of the first variant body 102A of the panel 450A (or light-transmission unit 101) of the optic device 400A to irradiate, via the light-output surface 120, an interior shaded space between two cultivation tiers (e.g. cultivation tiers 13A and 13B).

[00099] According to various embodiments, the optic device 400A may be coupled to the side of the cultivation column 13 (e.g. side of the upper cultivation tier 13A) in a manner such that the reference plane 25 (or the light-input surface 110) defined by the first edge 131 of the first planar side surface 130 and the first edge 141 of the second planar side surface 140 of the first variant body 102A (e.g. all first variant bodies 102A) of the panel 450A (or light-transmission unit 101) of the optic device 400A forms an angle within a range of 50° to 100° , or 50° to 90° , with respect to the column axis 19 of the cultivation column 13 (i.e. the reference plane may be pointing diagonally downward or horizontal or slightly diagonally upwards). In other words, for example, according to various embodiments, each panel 450A (or each first variant body 102A) of the optic device 400A, when secured to a side of a corresponding cultivation tier (e.g. side of the upper cultivation tier 13A) of the cultivation column 13, may have the reference plane 25 (or the light-input surface 110) of each first variant body 102A being parallel (e.g. substantially parallel) with an upward-facing surface (e.g. upward-facing surface 14A) of the corresponding tier. According to various other embodiments, each panel 450A (or each first variant body 102A) of the optic device 400A, when secured to a side of a corresponding cultivation tier (e.g. side of the upper cultivation tier 13A) of the cultivation column 13, may have the reference plane 25 (or the light-input surface 110) of each first variant body 102A slanting downwards (e.g. forming an angle of approximately 60°) with respect to an upward-facing surface (e.g. upward-facing surface 14A) of the corresponding tier.

[000100] According to various embodiments the optic device 400A may be coupled to the side of the cultivation column 13 (e.g. side of the upper cultivation tier 13A) with the second planar side surface 140 of the first variant body 102A (e.g. all first variant bodies 102A) of the panel 450A (or light-transmission unit 101) of the optic device 400A directed towards the side of the cultivation column 13 and with the first planar side surface 130 of the first variant body 102A (e.g. all first variant bodies 102A) of the panel 450A (or light-transmission unit 101) of the optic device 400A directed away from the side of the cultivation column 13. In other words, the second planar side surface 140 of the first variant body 102A (e.g. all first variant bodies 102A) may be directed inwardly, while the first planar side surface 130 of the first variant body 102A (e.g. all first variant bodies 102A) may be directed outwardly. As an example, the light-output surface 120 of each first variant body 102A of the optic device 400A, when secured to a side of an upper cultivation tier 13A of the cultivation column 13, may be facing or directed downwards towards a lower cultivation tier 13B of the cultivation column 13 with respect to the column axis 19.

[000101] Accordingly, with reference to FIG. 4A and FIG. 4B, at least a portion of light that enters each first variant body 102A of the optic device 400A via the light-input surface 110 of the first variant body 102A (e.g. all first variant bodies 102A), with an entry angle in or within a range from 0° to 90° (inclusive of 0° and 90°) measured from the normal 27 of the reference plane 25 of the first variant body 102A, may be redirected by said first variant body 102A to exit from the light-output surface 120 of the first variant body 102A, at an exit angle in or within a range from 180° to 270° measured from the normal 27 of the reference plane 25, with the exiting light being distributed to a lower and/or the inner region (e.g. the lower cultivation tier 13B) of the cultivation column 13 that the light-output surface 120 may be generally facing or directed towards. Further, the light redirected by the first variant bodies 102A may be spread substantially evenly or uniformly.

[000102] As shown in FIG. 4A, each panel 450A may be secured to a respective (e.g. corresponding one) side of the cultivation column 13, and the panel 450A may run or extend (e.g. continuously, without interruption) along an entire length of that side of the cultivation column 13 (in other words, an entire length of the tier or platform of the cultivation column 13 to which the panel 450A is attached or secured). That is, a length of the panel 450A may be equal (e.g. substantially equal) to a length of a side of a tier

of the cultivation column 13. As also shown, two disparate panels 450A may be secured on opposite sides (e.g. one panel 450A on each side) of a tier (e.g. cultivation tier 13A) of the cultivation column 13. Accordingly, according to various embodiments, the cultivation system 460 may include at least two panels 450A, and the at least two panels 450A may be respectively coupled to two opposite sides of a tier (e.g. cultivation tier 13A) of the cultivation column 13 of the cultivation system 460.

[000103] According to various other embodiments (not shown), a plurality of disparate panels 450A may be secured to a respective (e.g. one) side of a tier of the cultivation column 13, with a spacing or gap between adjacent or neighboring panels 450A along that side of the tier of the cultivation column 13. In this arrangement, according to various other embodiments, the disparate panels 450A along a single side of a tier of the cultivation column 13 may be arranged (e.g. “tailored”) to distribute light to targeted areas (e.g. of lower tier 13B) within the cultivation column 13.

[000104] Accordingly, according to various embodiments, a plurality of panels (e.g. two or more panels 450A) may be modularly arranged (e.g. on a cultivation column 13) and/or may be joined or coupled to other panel(s) for redirecting Sunlight or artificial light from side(s) of the cultivation column 13 (i.e. to which panel(s) are secured) into lower and/or inner region(s) (e.g. of cultivation tiers) within the cultivation column 13.

[000105] In an example involving the use of Sunlight (or Sunlight irradiance, or photosynthetically active radiation), the Sunlight that is incident on the panel(s) 450A (e.g. on the light-input surfaces 110 of the first variant body/bodies 102A of the panel(s) 450A) which are secured to side(s) of the cultivation column 13 (e.g. to the upper tier 13A) may be redirected by the panel(s) 450A to area(s) (e.g. shaded area(s), or inner region(s)), e.g. on the lower tier(s) or platform(s) (e.g. lower tier 13B) of the cultivation column 13 (e.g. for cultivating plants or other organisms). Specifically, the panel(s) 450A mounted along the side(s) of upper tier(s) or platform(s) of the cultivation column 13 may redirect Sunlight from the side(s) of and/or from overhead the cultivation column 13 to shaded area(s) on lower tier(s) or platform(s) of the cultivation column 13.

[000106] According to various embodiments, the panel 450A (or each first variant body 102A) of the optic device 400A may target or redirect light (e.g. Sunlight) to shaded region(s) (e.g. the upward-facing surface 14B of the lower cultivation tier 13B) within the cultivation column 13 that may require illumination, while maintaining

sufficient levels of irradiation (e.g. PAR irradiation) uniformly across the region(s) being illuminated by the redirected light. In practice, such irradiation uniformity of redirected light, which may be achievable with the optic device 400A according to various embodiments, may be required for cultivation of produce (e.g. plant or other organism).

[000107] According to various embodiments, each panel 450A (or each first variant body 102A) of the optic device 400A may be configured in a manner so as to perform optimally (e.g. be efficient / highly efficient) when an elevation (or angle) of a light source (e.g. the Sun or an artificial light source) with respect to a corresponding (or each) reference plane 25 (e.g. horizontal reference plane) of a corresponding (or each) first variant body 102A is between or within a range of 60° to 90° (inclusive of 60° and 90°). Such a light source elevation may coincide with a period of time of day within which a cumulative solar irradiation (e.g. by the Sun) may be 67% (e.g. approximately 67%) of a total daily solar irradiation.

[000108] According to various embodiments, each cultivation column 13 may be orientated along a North-South axis or North-South orientation, or an East-West axis or East-West orientation, in other words, the side(s) of the cultivation column 13 at which the one or more panel(s) 450A are mounted may be aligned to a North or a South direction, or an East or a West direction, for optimizing or maximizing an amount of Sunlight that may be received and redirected by the panel(s) 450A. More specifically, the cultivation column 13 may be positioned or arranged between an azimuth within -30° to 30° (e.g. $+30^\circ$) and/or oriented along (e.g. approximately along) the North-South axis (e.g. with a tolerance of $\pm 30^\circ$) or within 60° to 120° and/or oriented along (e.g. approximately along) the East-West axis (e.g. with a tolerance of $\pm 30^\circ$). In other words, the cultivation column 13 may be oriented with the side(s) of the cultivation column aligned to an azimuth within a range from -30° to 30° with reference to true north. Optionally, the cultivation column 13 may be positioned or arranged between an azimuth within 60° to 120° with reference to true North and/or oriented along (e.g. approximately along) the East-West axis (e.g. with a tolerance of $\pm 30^\circ$).

[000109] According to various embodiments, the cultivation column 13 may be deployed in tropical climates where a Sun position at solar noon time is usually high on many days throughout a year. For example, the cultivation column 13 may be deployed in tropical and subtropical locations or regions between latitudes $\pm 40^\circ$.

[000110] According to various embodiments, the cultivation column 13 may be deployed or positioned or disposed in or within or on open-air space or an open space (e.g. rooftop or field) or greenhouse or outdoor roofless enclosure (represented by schematic 16 in FIG. 4A) where the system 460 may be exposed (e.g. directly exposed) to direct Sunlight or partial direct Sunlight. According to various embodiments, the system 460 may include the greenhouse or the outdoor roofless enclosure 16. Accordingly, the cultivation column 13 may be disposed inside the greenhouse or within the outdoor roofless enclosure 16. For example, the cultivation column 13 may include a base support 15 for positioning or resting the cultivation column 13 on a floor of the greenhouse or outdoor roofless enclosure 16.

[000111] Accordingly, according to various embodiments, each tier or platform 13A, 13B of the cultivation column 13 may be a single trough or a series of hydroponic ducts arranged side-by-side and/or parallel to each other for containing soil or soil-less media for deep-water hydroponics. Further, each tier or platform 13A, 13B of the cultivation column 13 may include of a series of ducts (e.g. arranged adjacent and parallel to each other) for nutrient film technique (NFT) hydroponics.

[000112] FIG. 4D is a perspective view of a cultivation system 460B including four cultivation columns 13, according to various embodiments.

[000113] As shown in FIG. 4D, the cultivation system 460B may include a plurality of (e.g. two) cultivation columns 13 arranged or positioned adjacent to each other (e.g. in an end-to-end manner) to form a row of cultivation columns 13, and multiple rows of cultivation columns 13 may be arranged alongside each other with a space or gap separating adjacent or neighboring rows of cultivation columns 13 that may serve as a pathway 18 (e.g. a service corridor) for personnel (e.g. workers) and/or for equipment to pass therethrough.

[000114] FIG. 4E is a perspective view of a cultivation system 460C including a cultivation column 13, in the form of a cultivation rack 23, with three cultivation tiers, at least one panel 450A mounted to at least one side of a topmost cultivation tier of the cultivation rack 23, and at least one panel 450A mounted to at least one side of a middle (i.e. second) cultivation tier of the cultivation rack 23, according to various embodiments. According to various embodiments, the cultivation column 13 may be the cultivation rack 23. The cultivation tier(s) of the cultivation column 13 may be one or more cultivation bench/benches 23A, 23B, 23C of the cultivation rack 23, and the

side(s) of the cultivation column 13 may be side(s) of the cultivation bench/benches 23A, 23B, 23C of the cultivation rack 23.

[000115] FIG. 4F is a perspective view of a cultivation system 460D including a cultivation column 13 in the form of a cultivation wall 33 (e.g. vertical-walled, or grow wall) having at least six cultivation tiers (e.g. wall troughs or shelves) and at least one panel 450A mounted to at least one side of a topmost part of the cultivation wall 33, according to various embodiments. According to various embodiments, the cultivation column 13 may be the cultivation wall 33. The cultivation tier(s) of the cultivation column 13 may be one or more cultivation shelf/shelves 33B, 33C, 33D, 33E, 33F, and the side(s) of the cultivation column 13 may be side(s) of the cultivation wall 33A (as shown in FIG. 4F) or side(s) of the cultivation shelf/shelves 33B, 33C, 33D, 33E, 33F.

[000116] Accordingly, a panel of an optic device, according to various embodiments, may be attached to any type of cultivation column (e.g. multi-tiered rack, vertical-walled, or grow wall), for example, the three-tiered cultivation rack 23 of FIG. 4E or the cultivation wall 33 of FIG. 4F.

[000117] FIG. 5A show images depicting simulations of light paths of Sunlight incident on a cultivation column 53A and at least one panel 550A secured to a side of the cultivation column 53A, when Sun elevation is at 60°, 75°, and 90° (e.g. with reference to a reference plane or a light-input surface of at least one or all light-transmitting body/bodies of each panel 550A), respectively, according to various embodiments.

[000118] The simulations depicted by FIG. 5A may be based on ray-tracing simulations which may be used to predict light path of Sunlight (e.g. incoming Sunlight) at various Sun elevation angles with respect to the simulated cultivation column 53A and panel(s) 550A, according to various embodiments.

[000119] From the simulations, it may be observed that there can be significant redirection of light rays towards initially shaded areas or parts of a lower tier or platform (e.g. grow bed) of the cultivation column 53A, when at least one panel 550A is attached to a side of an upper tier or platform of the cultivation column 53A for redirecting light rays (e.g. from the Sun) to the lower tier or platform.

[000120] As a result of the configuration (e.g. shape, form, curvature, etc.) of the panel 550A, according to various embodiments, redirection efficiency or transmission efficiency (e.g. of the Sunlight), by the panel 550A, to the shaded areas or parts within

the cultivation column 53A may be between 50% to 65% when Sun elevation angle is within or between 60° to 90° (in other words, inclusive of 60° and 90°). Further, as a result of the redirected Sunlight by the panel 550A, according to various embodiments, initially shaded zones within or on the lower tier or platform of the cultivation column 53A may be exposed to or illuminated with the Sunlight. In particular, each panel 550A, according to various embodiments, may diffuse and/or distribute the Sunlight (i.e. that entered the body/bodies of the panel 550A) onto an extended region on the lower tier or platform (e.g. approximately 20 cm to 30 cm from an edge of a shadow boundary).

[000121] The simulations also show controlled redirection of the Sunlight by the panel 550A, according to various embodiments, to a relatively large area of a tier or platform (e.g. the lower tier or platform).

[000122] FIG. 5B depict simulated and experimentally obtained “irradiance maps” based on light from a light source (e.g. simulating the Sun) being redirected by a simulated/prototype panel which includes a plurality of first variant bodies 102A onto a lower cultivation tier (e.g. lower platform of a cultivation column) positioned 50 cm from the simulated/prototype panel (e.g. from a reference plane of the simulated/prototype panel), when the incident light angle (e.g. the angle of the light source with respect to the reference plane of the simulated/prototype panel) is at 60°, 75° and 90°, respectively, according to various embodiments.

[000123] From FIG. 5B, it may be observed that the simulated/prototype panel may be capable of redirecting light (e.g. from the external light source) onto areas (e.g. initially shaded areas) of a lower cultivation tier of a cultivation column which may not be capable of receiving direct light from the external light source (e.g. due to the light paths of the external light source being blocked by an intermediate physical obstruction, i.e. upper cultivation tier). The simulated irradiation map may be corroborated by the empirical light measurement data.

[000124] FIG. 5C is a graph depicting solar angle with respect to redirection efficiency, based on a simulated/prototype panel which includes a plurality of first variant bodies 102A, according to various embodiments.

[000125] Herein, “redirection efficiency” may be defined as the ‘power (e.g. irradiance or light) received on a tier’ over ‘power (e.g. irradiance or light) incident on a panel (or a body of the panel)’. A formula for deriving a percentage of “redirection

efficiency” (%R) may be as follows: $\%R = [(\text{Redirected power received at target plane}) / (\text{power incident on panel})] \times 100$.

[000126] As seen from FIG. 5C, at a relatively high Sun elevation angle (e.g. between or within a range of 60° to 90°), 50% to 65% of the incoming radiation (i.e. light that is incident on and that enters the body/bodies of the simulated/prototype panel) may be redirected by the simulated/prototype panel onto a lower cultivation tier (e.g. lower platform of a cultivation column).

[000127] FIG. 5C also show that there may be more than 48% redirection efficiency when Sun elevation is within 60° to 90° (which may account for 67% of cumulative PAR in a day).

[000128] FIG. 5D and FIG. 5E depict simulated “irradiance maps” based on light from a light source (e.g. simulating the Sun) being redirected by (i) a simulated panel which includes a plurality of first variant bodies 102A as well as by (ii) a simulated panel which includes a plurality of second variant bodies 102B, onto a lower cultivation tier (e.g. lower platform of a cultivation column) positioned 50 cm from the simulated panel (e.g. from a reference plane of the simulated panel), when the incident light angle (e.g. the angle of the light source with respect to the reference plane of the prototype panel) is at 60°, 75° and 90°, respectively, according to various embodiments.

[000129] From FIG. 5D and FIG. 5E, it may be observed that the simulated panel which includes a plurality of first variant bodies 102A may be capable of spreading or distributing a light exiting from the panel well (e.g. uniformly) across a lower cultivation tier, which may be attributed to the curved light-output surface 120 (e.g. light exiting face) of each first variant body 102A of the panel. Having the “over-hanging portion” (e.g. the corner portion 290) is shown to enhance the spreading and/or uniformity of redirected light (e.g. light exiting from the panel) by each first variant body 102A of the panel onto and/or across the lower cultivation tier. In other words, the curved surface profile and the “over-hanging portion” of a light-output surface of an optic device, according to various embodiments, may contribute or help spread and/or distribute irradiation of Sunlight uniformly across a cultivation tier, in particular, for example, over a wide range of solar elevation angles (e.g. 60° to 90°). Moreover, the “over-hanging portion” may allow for or enable a long (or longer) curvature length (e.g. a long / longer curved light-output surface 120), which may enhance the spreading of light and/or provide improved irradiance uniformity, while limiting a total width of

a body or panel (e.g. not require a very thick body or panel) according to various embodiments.

[000130] FIG. 5F is a table showing irradiance uniformity ratios of the first and second variant body/bodies 102A, 102B based on redirected irradiance on an area of interest (e.g. which may occupy an entire simulated length of a cultivation tier and may extend 25 cm from a shadow boundary), according to various embodiments.

[000131] FIG. 6A and FIG. 6B show a prototype light transmission unit (or panel 650), according to various embodiments.

[000132] According to various embodiments, the panel 650 may be a prototype based on the panel 350A of FIG. 3A.

[000133] As shown, according to various embodiments, the panel 650 may include a plurality of (e.g. five) first variant bodies 102A (e.g. five subunits).

[000134] As shown, according to various embodiments, each first variant body 102A of the panel 650 may, similar to the panel 350A of FIG. 3A, include a light-input surface, a light-output surface having a first curved surface portion and second curved portion, a first planar side surface, and a second planar side surface.

[000135] FIG. 7A shows a perspective view of a prototype optic device 700 with a light transmission unit (or panel 750) and an attachment member 77 which includes an extension element 77a, according to various embodiments.

[000136] According to various embodiments, the panel 750 may be a prototype based on the panel 350A of FIG. 3A.

[000137] As shown, according to various embodiments, the panel 750 may include a plurality of (e.g. six) first variant bodies 102A (e.g. six subunits).

[000138] As shown, according to various embodiments, each first variant body 102A may, similar to the panel 350A of FIG. 3A, include a light-input surface, a light-output surface having a first curved surface portion and second curved portion, a first planar side surface, and a second planar side surface.

[000139] Further, as shown, the optic device 700 may include the attachment member 77 for securing the panel to a side of a cultivation column (e.g. mock-up rack model for simulating a cultivation column). As shown, the attachment member 77 may include the extension element 77a extending from an outermost first variant body 102A of the plurality of first variant bodies 102A of the panel 750 and a fastener 77b which may secure the extension element 77A to the side of the cultivation column.

[000140] FIG. 7B to FIG. 7D show various views of a prototype optic device 700B with a light transmission unit (or panel 750B) and an attachment member 77 which includes a bracket 78b.

[000141] As shown, according to various embodiments, the panel 750B may include a plurality of light-transmission bodies 702A, 702B (e.g. five subunits).

[000142] As shown, according to various embodiments, each light-transmission body 702A, 702B may, similar to the panel 350A of FIG. 3A, include a light-input surface, a light-output surface having a first curved surface portion and second curved portion, a first planar side surface, and a second planar side surface.

[000143] As shown, according to various embodiments, the curved surfaces of the light-output surfaces of the plurality of light-transmitting bodies 702A, 702B forming the panel 750B may have different curvatures (in other words, different curved shapes) from each other. In other words, according to various embodiments, the panel 750B may include a combination of subunits (e.g. five or any other number of subunits) in which two or more subunits of the panel 750B may have different curvatures of light-output surfaces from each other.

[000144] Further, as shown, the optic device 700B may include the attachment member 77 for securing the panel to a side of a cultivation column. As shown, the attachment member 77 may include the bracket 78b. Further, the attachment member 77 may include at least one fastener 77b which may secure the panel 750B to the bracket 78b (e.g. via an extension element 78a of the panel 750B) and at least one other fastener 77b which may secure the bracket 78b to the side of the cultivation column.

[000145] According to various embodiments, the bracket 78b may be capable of being malleable. For example, the bracket 78b may include or may be made of a material such as a metal (e.g. malleable metal), a polymer or plastic (e.g. malleable polymer or plastic), etc. Accordingly, as shown in FIG. 7C, according to various embodiments, the bracket 78b may be configured such that that panel 750B may be coupled to a side of a cultivation column in a manner so as to form an overhang protruding from the side of the cultivation column, with a reference plane of the light-input surface of each of the light-transmitting bodies 702A, 702B of the panel 750B being parallel (e.g. substantially parallel) with a cultivation tier (e.g. planar cultivation tier) of the cultivation column. Alternatively, as shown in FIG. 7D, according to various other embodiments, the bracket 78b may be configured such that that panel 750B may

be coupled to a side of a cultivation column in a manner so as to form an overhang protruding from the side of the cultivation column, with the reference plane of the light-input surface of each of the light-transmitting bodies 702A, 702B of the panel 750B being non-parallel (in other words, inclined or at an angle) with respect to the cultivation tier (e.g. planar cultivation tier) of the cultivation column.

[000146] FIG. 8A shows a set-up for conducting an experiment involving a prototype panel 850 based on the light transmission unit (e.g. panel 350A) of FIG. 3A, according to various embodiments; and FIG. 8B is schematic side view depicting conditions for the experiment that involves the prototype panel 850 based on the panel 350A of FIG. 3A, according to various embodiments.

[000147] With reference to FIG. 8A and FIG. 8B, the prototype panel 850 was tested under actual direct Sunlight to evaluate the panel's 850 performance under natural or actual conditions.

[000148] Specifically, preliminary measurements were conducted with a Sun elevation hovering between 69° to 74° with respect to a reference plane of one or all light-emitting body/bodies of the panel 850. Photosynthetically active radiation (i.e. PAR) sensors 88 were installed at 10 cm (ΔW) intervals along the width of the cultivation column and 50 cm (ΔH) vertically below the panel 850 position. Measurements were carried out both with and without the presence of the prototype panel 850.

[000149] FIG. 8C shows the graphs of the measured Photosynthetic photon flux density (PPFD) values with respect to time at various positions from 10 cm to 50 cm, based on the experiment of FIG. 8B, according to various embodiments. FIG. 8D is a graph showing the cumulative PAR irradiation received at various positions along the width of the cultivation column of FIG. 8A, based on the experiment of FIG. 8B, according to various embodiments.

[000150] As shown in FIG. 8C, the preliminary data show improvements in the PPFD received in the shaded areas (e.g. of a shaded cultivation tier of a cultivation column) in the presence of the prototype panel (i.e. corresponding to a light redirection panel of various embodiments) at all positions along the width of the cultivation column. The increase in PPFD is even more prominent between 10 cm to 30 cm from an edge of a shadow boundary.

[000151] The cumulative PAR over the period monitored are shown in FIG. 8D. Over the course of 1 hour, it was found that the panel on a single side/edge of a cultivation column can potentially increase the PAR irradiation by 20% to 64% at various positions from the side/edge. Thus, when panels are secured to both (e.g. opposite) sides/edges of a cultivation column, the panels could potentially boost daily light integral (DLI) received by plants or organisms cultivated on a lower cultivation tier of the cultivation column in the day.

[000152] As shown, there is a 64% increase in cumulative PAR within 20 cm from an edge of a platform (e.g. grow bed).

[000153] Various embodiments may thus provide an optic device which may be capable of redirecting light from an edge of an upper tier (e.g. roof) of a multi-tiered structure (e.g. cultivation column) to shaded regions of a lower tier (e.g. platform) of the multi-tiered structure, which may be used for plant or organism cultivation on the lower tier of the multi-tiered structure.

[000154] The optic device according to various embodiments may be simple to fabricate, and may be easy to install or secure to a side of a multi-tiered structure.

[000155] Further, various embodiments may provide an optic device which may operate using only natural light from the Sun, thereby reducing or minimizing carbon footprint. By being capable of operating without electrical power, the optic device according to various embodiments are also cost-effective to operate and to maintain.

[000156] While the invention has been particularly shown and described with reference to specific embodiments, it should be understood by those skilled in the art that various changes, modification, variation in form and detail may be made therein without departing from the scope of the invention as defined by the appended claims. The scope of the invention is thus indicated by the appended claims and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced.

CLAIMS

1. An optic device comprising:
 - a light-transmission unit comprising a light-transmitting body, the light-transmitting body comprising:
 - a light-input surface for a light to enter the light-transmitting body;
 - a light-output surface for the light to exit the light-transmitting body;
 - a first planar side surface extending between the light-input surface and the light-output surface, wherein the first planar side surface adjoins the light-input surface at a first edge of the first planar side surface;
 - a second planar side surface opposite to and parallel with the first planar side surface, wherein the second planar side surface adjoins the light-input surface at a first edge of the second planar side surface, wherein the first edge of the first planar side surface and the first edge of the second planar side surface are parallel to each other and define a reference plane;
 - wherein the first planar side surface forms a non-zero acute internal angle with the reference plane;
 - wherein at least a region of the light-output surface is offset from at least a region of the light-input surface in an offset direction corresponding to a direction extending from the first planar side surface to the second planar side surface in a manner substantially parallel with the reference plane;
 - wherein the light-output surface comprises a curved surface extending from a second edge of the first planar side surface and curves away from the first planar side surface in the offset direction, the second edge of the first planar side surface being opposite the first edge of the first planar side surface;
 - wherein the light-transmitting body is capable of redirecting a light entering the light-input surface with an entry angle within a range from 0 to 90 degrees measured from a normal of the reference plane, which is corresponding to a range of angles from the normal to a line extending perpendicularly from the first edge of the first planar side surface to the normal, to exit from the light-output surface at an exit angle within a range from 180 to 270 degrees measured from the normal of the reference plane.

2. The optic device of claim 1,
wherein the curved surface of the light-output surface extends from the second edge of the first planar side surface to a second edge of the second planar side surface, the second edge of the second planar side surface being opposite the first edge of the second planar side surface,
wherein a gradient of the curved surface of the light-output surface, with respect to the first planar side surface, progressively increases from the second edge of the first planar side surface to the second edge of the second planar side surface.
3. The optic device of claim 2,
wherein the light-transmission unit comprises a plurality of the light-transmitting bodies coupled together in a side-by-side arrangement to form a single unitary panel structure, wherein a corner portion of one of the plurality of light-transmitting bodies extend over the curved surface of the light-output surface of an adjacent light-transmitting body, wherein the corner portion is a corner which the curved surface of the light-output surface joins the second edge of the second planar side surface.
4. The optic device of claim 1,
wherein the light-input surface comprises a planar surface which coincides with the reference plane.
5. The optic device of claim 1,
wherein the light-input surface comprises a curved surface.
6. The optic device of claim 1,
wherein the non-zero acute internal angle is within a range from 40 to 80 degrees.
7. The optic device of claim 1,
wherein the light-transmitting body is of an elongated shape, wherein the first planar side surface and the second planar side surface are two opposite and parallel longitudinal side surfaces of the elongated shape.

8. The optic device of claim 1,
wherein the light-transmitting body is made of solid materials which are transparent to wavelengths within a range from 350 nm to 750 nm.
9. The optic device of claim 1,
wherein the light-transmission unit comprises a plurality of the light-transmitting bodies coupled together in a side-by-side arrangement to form a single unitary panel structure.
10. The optic device of claim 9,
wherein the curve surfaces of the light-output surfaces of the plurality of the light-transmitting bodies have different curvature.
11. The optic device of claim 1, further comprising:
an attachment member disposed at a side of the light-transmission unit for securing the optic device to an external structure.
12. The optic device of claim 1,
wherein the light-output surface further comprises a planar surface that extends between a distal edge of the curved surface of the light-output surface and the second edge of the second planar side surface, the distal edge of the curved surface of the light-output surface being an edge furthest away from the second edge of the first planar side surface.
13. A cultivation system, comprising
a cultivation column having two or more cultivation tiers arranged along a column axis; and
the optic device according to any one of claims 1 to 13, wherein the optic device is coupled to a side of the cultivation column in a manner so as to form an overhang protruding from the side of cultivation column with the light-input surface of the light-transmitting body of the light-transmission unit of the optic device

directed upwards with respect to the column axis of the cultivation column and the light-output surface of the light-transmitting body of the light-transmission unit of the optic device directed downwards with respect to the column axis of the cultivation column, wherein the light-transmission unit of the optic device is capable of directing the light incident on the light-input surface of the light-transmitting body of the light-transmission unit of the optic device to irradiate an interior shaded space between two cultivation tiers of the two or more cultivation tiers of the cultivation column via the light-output surface of the light-transmitting body of the light-transmission unit of the optic device.

14. The cultivation system as claimed in claim 13,

wherein the optic device is coupled to the side of the cultivation column in a manner such that the reference plane defined by the first edge of the first planar side surface and the first edge of the second planar side surface of the light-transmitting body of the light-transmission unit of the optic device forms an angle within a range of 50 to 100 degrees with respect to the column axis of the cultivation column.

15. The cultivation system as claimed in claim 13,

wherein the optic device is coupled to the side of the cultivation column with the second planar side surface of the light-transmitting body of the light-transmission unit of the optic device directed towards the side of the cultivation column and the first planar side surface of the light-transmitting body of the light-transmission unit of the optic device directed away from the side of the cultivation column.

16. The cultivation system as claimed in claim 13,

wherein the cultivation column is a cultivation rack, wherein the cultivation tier is a cultivation bench of the cultivation rack, and wherein the side of the cultivation column is a side of the cultivation bench of the cultivation rack.

17. The cultivation system as claimed in claim 13,

wherein the cultivation column is a cultivation wall, wherein the cultivation tier is a cultivation shelf, and wherein the side of the cultivation column is a side of the cultivation wall or a side of the cultivation shelf.

18. The cultivation system as claimed in claim 13,
wherein the cultivation column is oriented with the side of the cultivation column aligned to an azimuth within a range from -30 to 30 degrees or 60 to 120 degrees with reference to true north.
19. The cultivation system as claimed in claim 13 comprising at least two optic devices,
wherein the at least two optic devices are respectively coupled to two opposite sides of the cultivation column.
20. The cultivation system as claimed in claim 13, further comprising:
a greenhouse or an outdoor roofless enclosure,
wherein the cultivation column is disposed inside the greenhouse or within the outdoor roofless enclosure.