Presentation of proprietary Environmental Engineering solutions characterized by their comprehensive, multi-variant nature.

1. **Panel-modular layered wall system.** This is a modular system consisting of six variants used to create diverse architectural structures that simultaneously provide climate comfort. The concept of the solution is based on combining a rigid layered structure with planted, vegetating vegetation. The solution was the subject of patent applications filed with the EPO and USPTO in 2021, as well as with the patent office in India. Patents were granted by the USPTO in 2025 - **US 12,239,064** and by IP India in 2026 - (**202147050304**). The patent is granted by the EPO in 2026 - **EP3945778A4.**

2. **The second solution is the Panel-layered system for thermal insulation of shaded surfaces**, which is advantageously used in synergy with the **1. Panel-modular layered wall system**. The solution provides extensive possibilities for personalization in terms of shaping the external form and can be further developed for other applications. It is the subject of patent applications filed with the UPRP (**P.437721**) in 2021, as well as with the EPO and USPTO. Patents were granted by the EPO (**EP22169747**) in 2025 and by the USPTO (**US 12,595,660**) in 2026.

## Evolution of Green Infrastructure Systems: From the Layered Green Wall (LGW) Concept to the Industrial Panel Modular System (PMS)

This text analyzes the evolutionary process of original environmental engineering solutions, spanning from early concepts and prototypes of the **Layered Green Wall (LGW)** developed between 2014 and 2021—most notably the "Infinite Green" installation in Wrocław (European Capital of Culture 2016)—to the creation of the advanced, industrial-scale **Panel Modular System (PMS)** . The PMS represents an innovative fusion of a rigid support structure and integrated vegetation, forming a mass ecosystem designed to improve climate comfort by oxygenating, cooling, and humidifying the air, while simultaneously reducing micro-dust

The core of this study focuses on the technical characteristics of the system, which features a modular design consisting of six geometric variants: vertical, inclined, arch-barrel, spherical, cylindrical, and inclined-cylindrical. This versatility allows for flexible eco-architecture design in dense urban fabrics, where the system can multiply the biologically active surface area by up to twenty times relative to its ground footprint .

A crucial element of this development is the synergy between the PMS and a complementary solution: the **Panel-layer system for thermal insulation of shaded surfaces**. The author demonstrates the advantages of implementing this system in the upper sections of PMS structures as transparent skylights. This integration allows intensive daylight to penetrate the interior while effectively blocking infrared radiation, thereby preventing the space from overheating. Ultimately, the study presents a model for a self-regulating structure that, through its substantial volume of substrate and plant matter, acts as a potent tool against urban heat islands and significantly enhances rainwater retention.

# PANEL MODULAR SYSTEM OF LAYERED WALL (Panel Modular System-PMS)

**Abbreviations used in the text:** (LAYERED GREEN WALL – LGW) is the name of the solution concept. **Panel Modular System (PMS)** – the name of the system developing the LGW concept towards an industrial solution for mass and universal application.
PMS is based on the LGW solution, the first prototypes of which were created in Poznań in 2014, in cooperation with researchers from the UAM Botanical Garden and the Poznań University of Technology, and in Wrocław in 2015 on the occasion of WROCŁAW European Capital of Culture 2016, titled **"Infinite Green"**. The project website is: https://adamkalinowski.com/home,9,the_infinite_green_2015.html. This was a year-round project operating continuously from 2015 to 2021. In this facility, 60 species and 60 subspecies of perennials growing wild in Poland, as well as useful plants, were tested. Measurements of temperature, humidity, and sunlight were collected, which became the basis for a scientific publication available at: https://www.mdpi.com/731172.
The **PMS panel-modular layered wall system** is used to shape spatial structures that combine a load-bearing structure with vegetating vegetation. It provides users with climate comfort by delivering oxygenated air that is cleaned of **micro-dust**, cooled, and humidified, and also enables plant production in difficult spatial and climatic conditions. The system is a modern solution that can be installed in the form of independent self-supporting structures
or as an element of existing or planned building infrastructure. It combines the advantages of vertical **Green Wall** solutions with natural, horizontal vegetation conditions and a modular load-bearing structure, allowing for the configuration of structures with diverse shapes. Alongside free-standing closed or semi-closed structures (e.g., green pavilions or tunnels) and completely open ones (e.g., green barriers separating pedestrian and vehicle traffic or facade installations), the PMS system is utilized in **vertical farming**. It enables the year-round cultivation of useful and ornamental plants in urbanized Central European spaces devoid of biologically active surfaces, as well as in hot and dry climates where natural conditions hinder vegetation. A set of six system variants allows for the creation of eco-architectural objects where form and function
are strictly interconnected.
The widespread application of this solution in urban spaces would bring a noticeable synergy effect in the following aspects:

***1.environmental, 2. spatial, 3. functional-utility, 4. social, 5. cultural, and 6. economic.***

*Selected links to the PMS system and the LGW (Layered Green Wall) concept:*

2021https://register.epo.org/application?number=EP20784674&lng=en&tab=familyhttps://register.epo.org/application?number=EP20784674&lng=en&tab=family

2022 https://register.epo.org/application?number=EP22169747&lng=en&tab=family

Wybrane linki bibliograficzne:


2015 http://www.designboom.com/architecture/infinite-green-eco-sculpture-adam-kalinowski10-20-2015/
2015 http://inhabitat.com/the-infinite-green-is-a-living-looping-sculpture-covered-in-over-3000-plants/
2016 TOUCH DÉCOR, JAN-APRIL 2016 issue; www.touchdecor.com; (Hard copy)
2015 http://wroclaw.wyborcza.pl/wroclaw/1,35771,18647520,mieta-lawenda-i-gozdziki-nowa-instalacja-na-olbinie-wideo.html; (Hard copy)
2016 http://www.bryla.pl/bryla/7,85301,20515866,wroclaw-nieskonczony-zielony-czyli-co-moga-rosliny.html; Bryła, GW, Warszawa.
2016 http://adamkalinowski.com/assets/deco-167-taiwan-2016.pdf
2016 http://forecastpublicart.org/public-art-review/2017/03/the-infinite-green/
2016 "The Infinite Green", PUBLIC ART REVIEW, issue 55 , USA. (hard copy).
2017 https://www.braun-publishing.ch/en/landscape-architecture/compendium-of-landscape-architecture.html
2020 "The Green Structure for Outdoor Places in Dry, Hot Regions and Seasons"
2021 https://builderscience.pl/resources/html/article/details?id=217778

# Panel Modular System of a Layered Wall – Diagram of Climate Interaction in an Urban Environment https://layeredgreenwall.com/

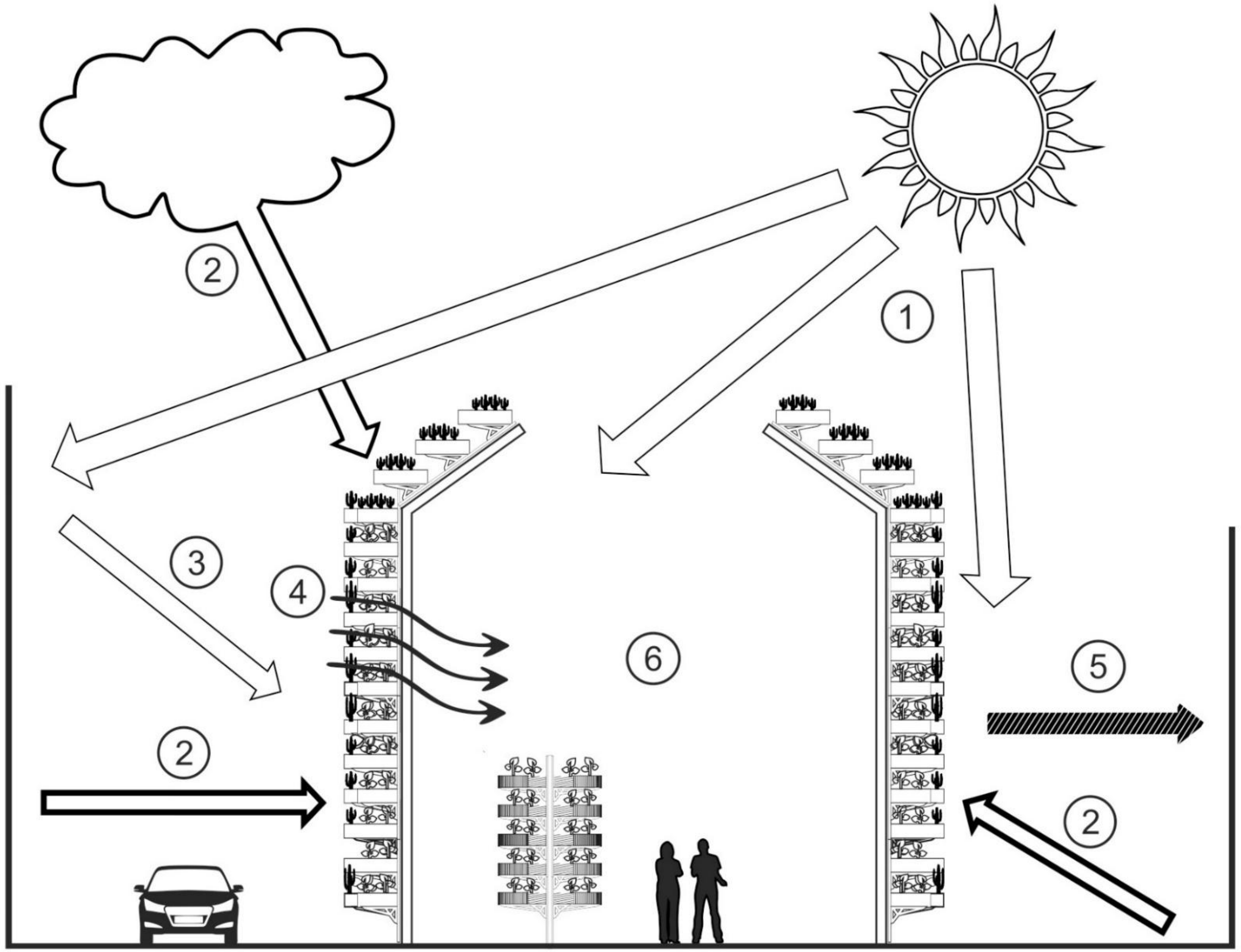


**Figure description:**

- **1. Solar radiation (short-wave);** {ultraviolet (7% energy), visible (45% energy), infrared (47% energy)}. Penetration of solar radiation into the interior of the layered structure through:
    - a. **Skylight** placed at the top level of the structure,
    - b. **Gaps** between the layers.

- 2. Thermal radiation (long-wave) emitted by the earth's surface and the atmosphere.

- 3. Reflected solar radiation, particularly intense in urbanized areas.

- 4. Local convection currents.

- 5. Impact of the structure on the surrounding climate – cooling of so-called urban heat islands.

- 6. Microclimate inside the structure.

https://layeredgreenwall.com/

- **Philosophy and Characteristics of the PMS System**
- **The idea behind the PMS solution is clear:** it aims to create a massive ecosystem friendly to every living being within the structure. In this way, the object becomes a kind of "home", modeled after the open space of the Earth, which is home to us all.
- **The volume of the construction is crucial** not only for ensuring climate comfort (in accordance with the UTCI index) but also for the survival of vegetation in extreme conditions—from desert areas to freezing winters in the Central European climate.
- **The foundation of this solution is the LGW (Layered Green Wall) concept**—a dynamic membrane combining a stable, self-supporting structure with vegetating plants that, by growing, seal the space between the layers.
- **Instead of isolating from the environment with solid walls**, the PMS system focuses on active cooperation with nature, which is a necessary condition for sustainable existence in cities.
- **Key advantages of the system:**

- 1. Modular simplicity: The system is based on two basic shapes—a triangle and a semicircle (and quadrants)—which allows for the creation of a large number of spatial combinations.
- 2. Intuitive assembly: Panels are connected by their edges (sides), creating a uniform, stable layer mounted on a supporting structure.
- 3. Vertical integration (silos): Layers are stacked, and every second or third panel is connected by a vertical silo filled with substrate. This allows water and microorganisms to move freely throughout the entire ecosystem. PMS thus constitutes a massive, coherent vegetation system that, unlike isolated pots, creates a powerful volume of greenery with a measurable impact on the local microclimate. With the support of photovoltaic cells (powering LED lighting, pumps, or ventilation), the structure becomes almost self-sufficient.
- 4. Effective water retention: The specific differentiation of the front plane of the panels allows for the capture of at least 25% of rainwater. This is a key feature in the face of the desertification of Europe and problems with rainwater drainage in cities.
- 5. Versatility of form: The system offers six variants (flat, inclined, arched, spherical, and cylindrical walls), which can be freely combined. This allows for the harmonious integration of structures even into the surroundings of historical, highly valuable European city buildings, avoiding a purely industrial aesthetic.
- 6. Utility and education: Beyond high aesthetic quality, the system performs an important social and educational function. An example is the "Infinite Green" object, which, through the use of 60 species and 60 subspecies of perennials, became a living, urban botanical garden.

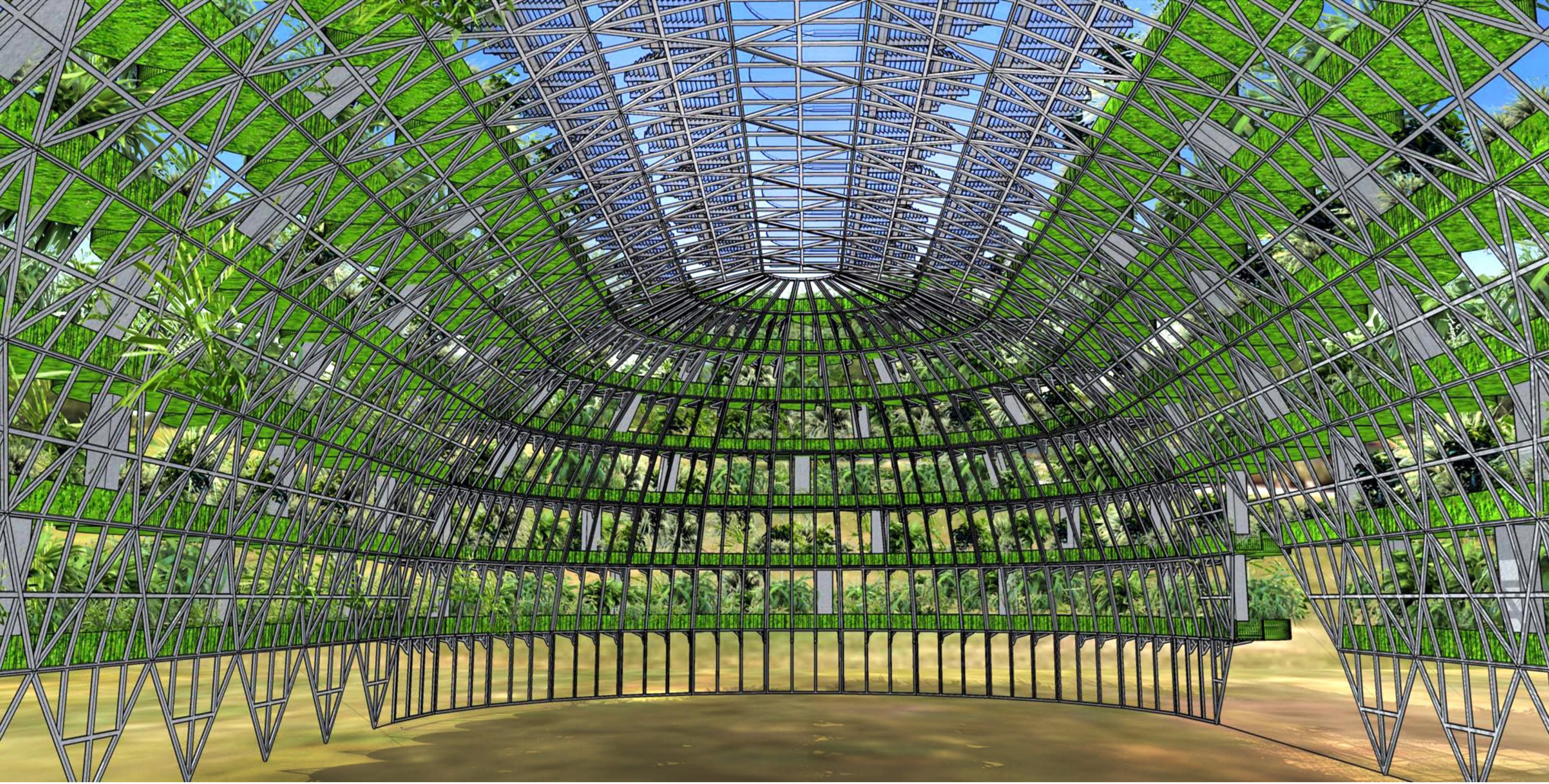
**"The Infinite Green", Wrocław, European Capital of Culture 2016, top view.**
An example of the application of the LGW (Layered Green Wall) conceptual solution, serving as a pre-prototype for the PMS system.
https://adamkalinowski.com/home,9,the_infinite_green_2015.html

**"The Infinite Green", Wrocław, European Capital of Culture 2016, side view.**

"The Infinite Green", Wrocław, European Capital of Culture 2016, side view.

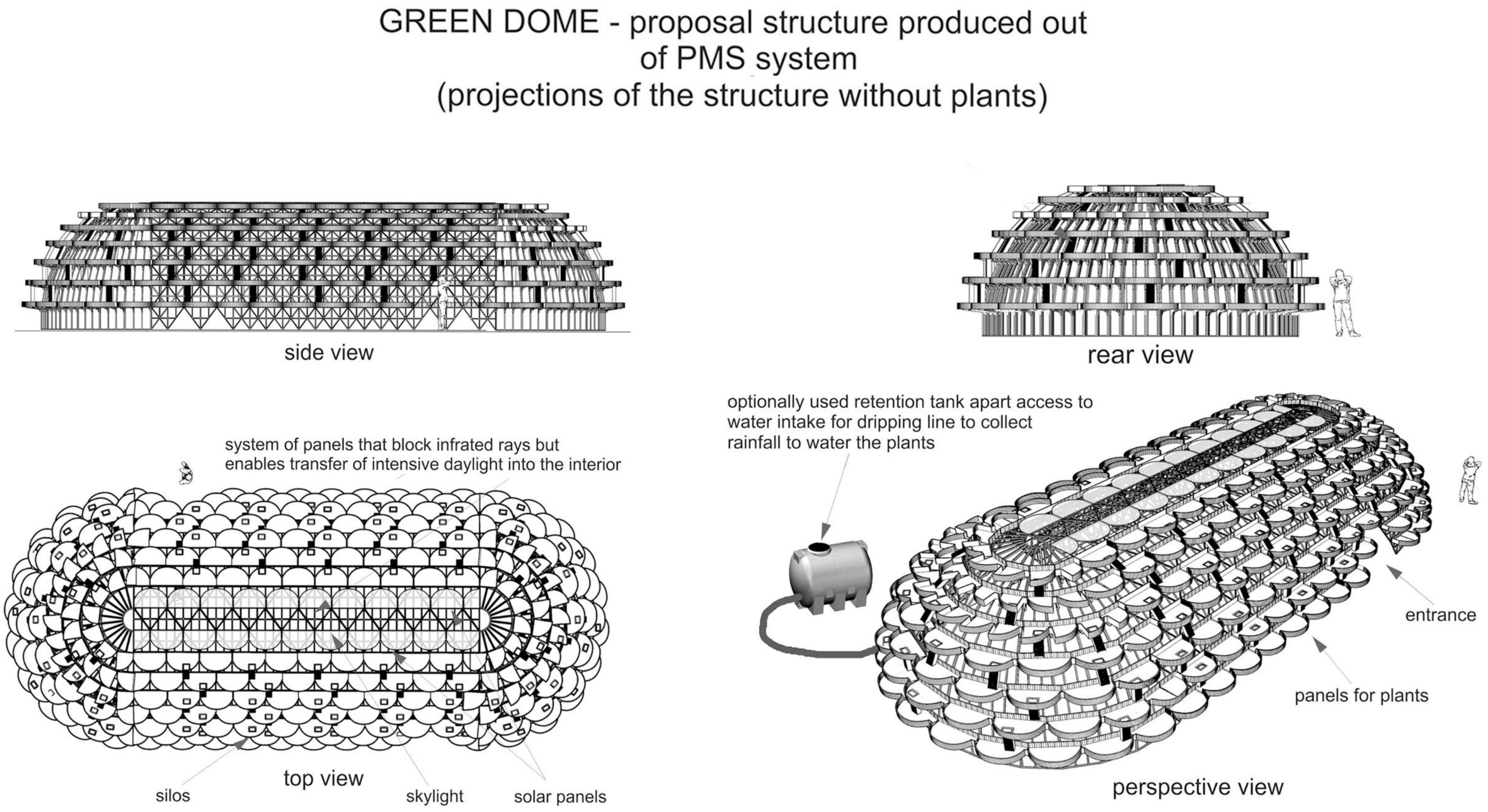
**"The Infinite Green", Wrocław, European Capital of Culture 2016, inner view.**

"Green Dome" – an example of a simple PMS structure built using two solution variants: arch-barrel and spherical; visualization.



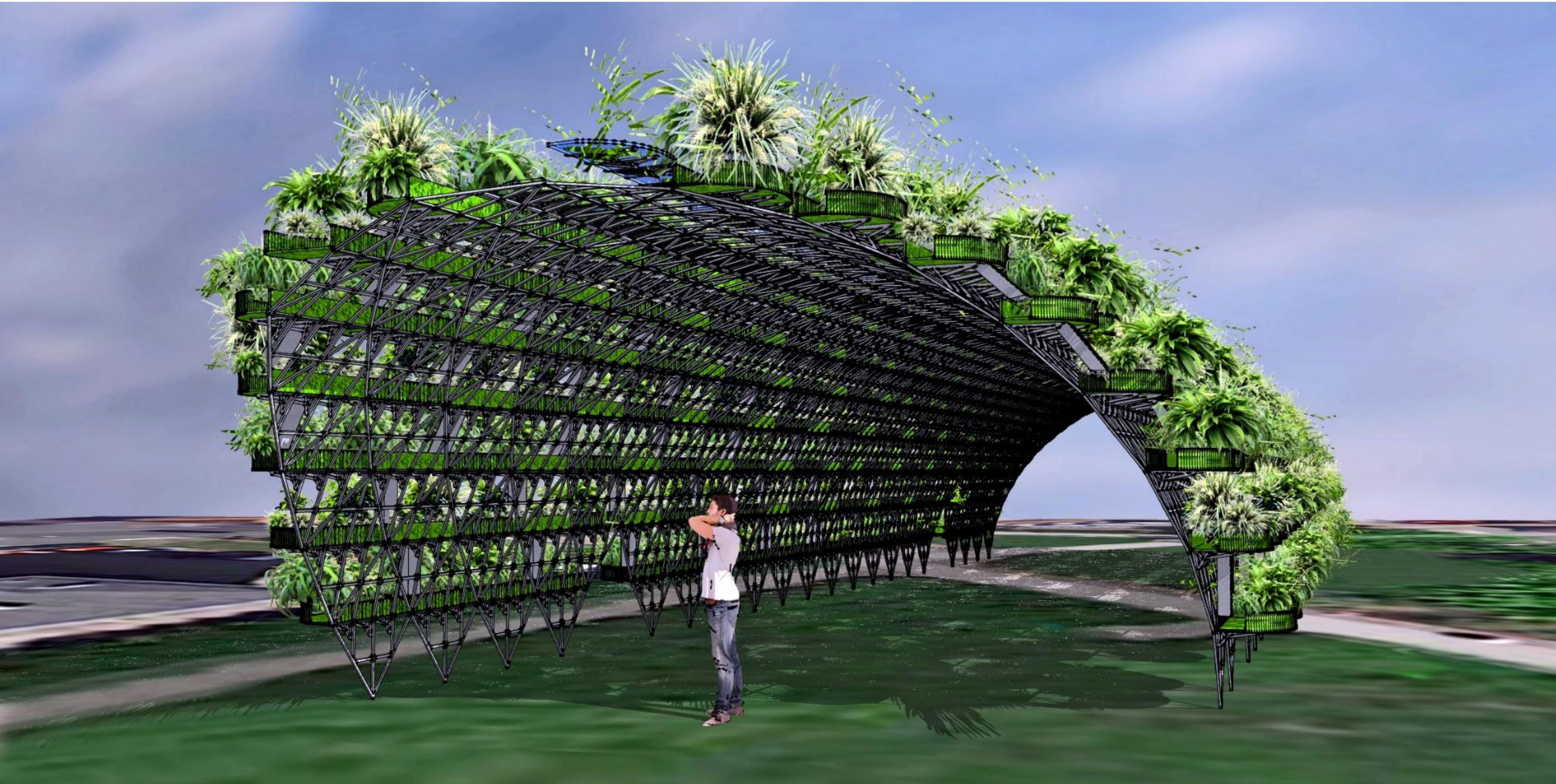
Green Dome – interior of the PMS structure

"Green Dome"; projections of an example structure – optional retention tank for collecting rainwater during rainfall in the autumn-spring period. https://layeredgreenwall.com/



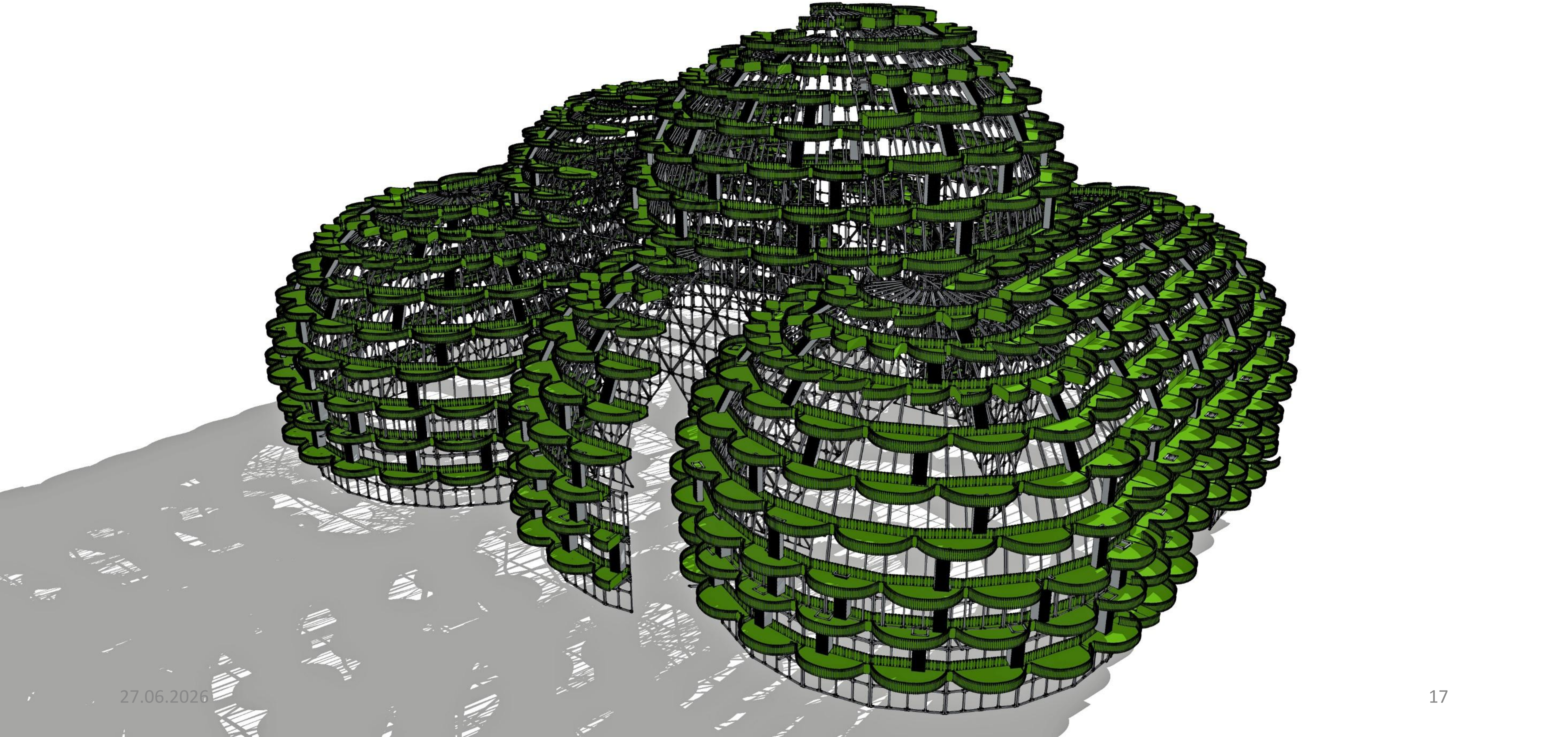
Example of a simple PMS structure with a spherical arrangement featuring an interactive art installation in the center; visualization.

Transfer tunnel along a street or as a link between buildings, arch-barrel vault variant; photovoltaic panels on top of the structure, visualization. https://layeredgreenwall.com/

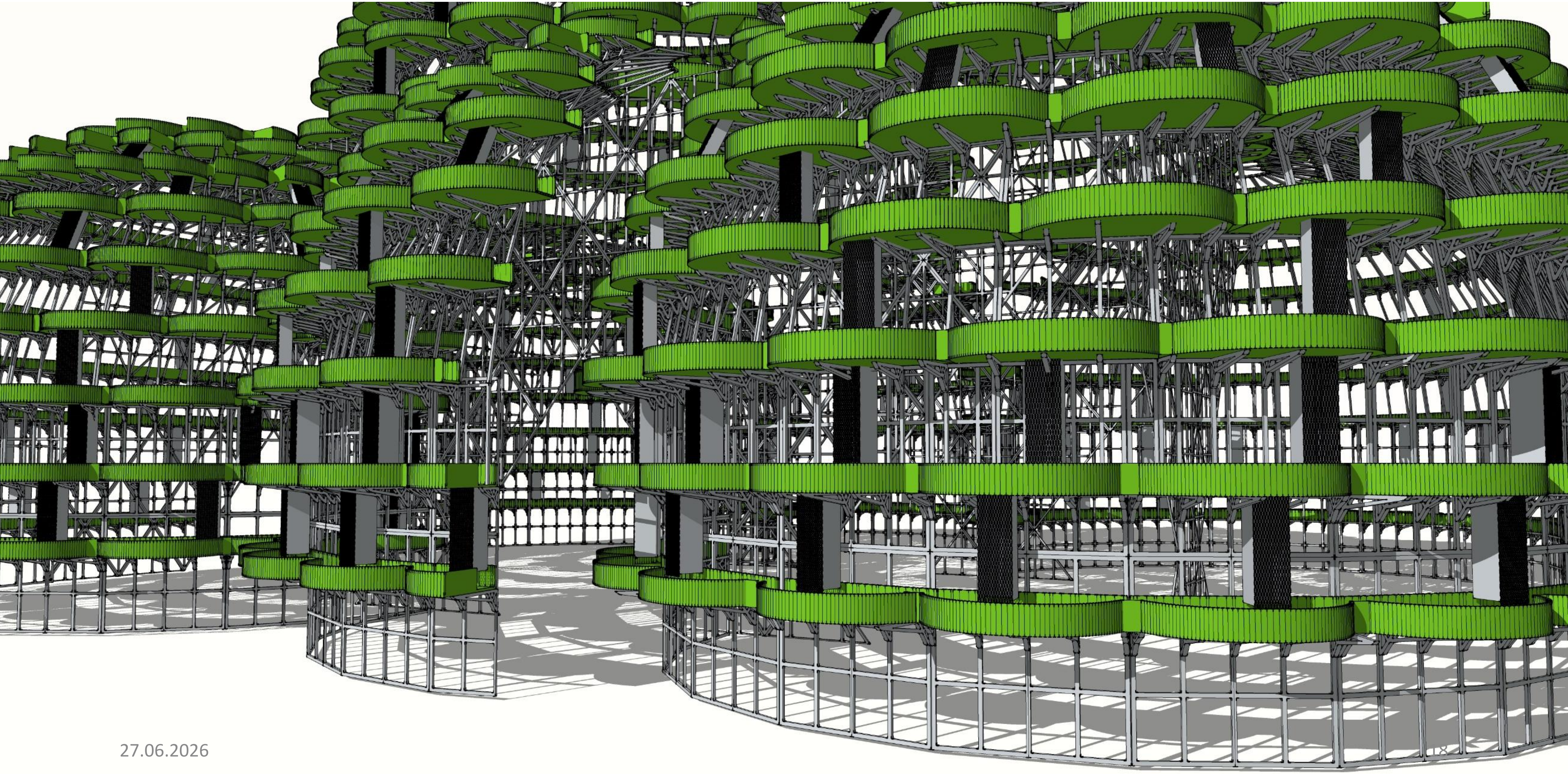


Arch-barrel and spherical structure placed on the roof of the building. Visible photovoltaic panels and skylights are designed to illuminate the interior without heating it. Visible vertical PMS elements mounted in pairs, planted with useful plants (urban farming).

Example of a larger-scale PMS structure shape, consisting of the arch-barrel and spherical PMS system variants (without vegetation), visualization.



One of the entrance openings to the interior of the PMS structure; visualization.



**Social effects resulting from the implementation of the PMS solution in the city.**

The system enables the construction of free-standing green structures (pavilions, tunnels, road barriers) and facade installations. Beyond microclimate optimization, the solution is dedicated to urban farming. It provides stable conditions for year-round cultivation of ornamental and useful plants both in Central European cities and in difficult desert climate conditions, where vegetation is naturally hindered.

https://layeredgreenwall.com/

**The implementation of the Panel Modular System (PMS) in the dense urban fabric generates multidimensional social effects that go beyond mere aesthetic improvement, becoming a tool for community building and enhancing the quality of life for residents.**
**Key social effects defined in the documentation:**

**1. Improvement of well-being and climate comfort (UTCI)**

**Haven in the heat:** By creating a microclimate (lowered temperature, higher humidity), PMS structures (e.g., "Green Domes") become popular destinations for residents during the day, especially during summer heatwaves and siesta.

**Health protection:** The system tangibly affects public health through oxygenation, humidification, and the cleaning of air from **micro-dust**, which is crucial in areas with high traffic volume.

**Stress reduction:** Being inside massive plant structures provides a shield from the scorching sun and reduces urban noise, creating zones of respite.

**2. Community integration and "Urban Farming"**

**Building collectives:** The PMS system enables urban farming, which focuses the local community's attention on a common goal, fostering the creation of collectives centered around urban agriculture. It is important to ensure easy access to the structure's layers for this purpose. To avoid access issues, the farming levels should not be placed higher than approximately 3 meters. Higher levels can be planted with ornamental plants where frequent access is not required.

**Cooperative activity:** Implementing "Urban Farming" processes through local cooperatives generates direct social and economic benefits for residents.

**Combating alienation:** Community gardens created based on PMS in city centers counteract the high levels of anonymity and alienation typical of urbanized areas.

**3. Educational Function and "Social Laboratory**

**Open Botanical Garden:** Due to its biodiversity (e.g., the use of 60 plant species in a single object), these structures serve as mini-botanical gardens accessible to every resident.

**Knowledge Laboratory:** These facilities become "social laboratories" where residents can learn about plant species, herbs, and ecosystems through direct contact with nature.

**4. Triggering Empathy and Co-responsibility**

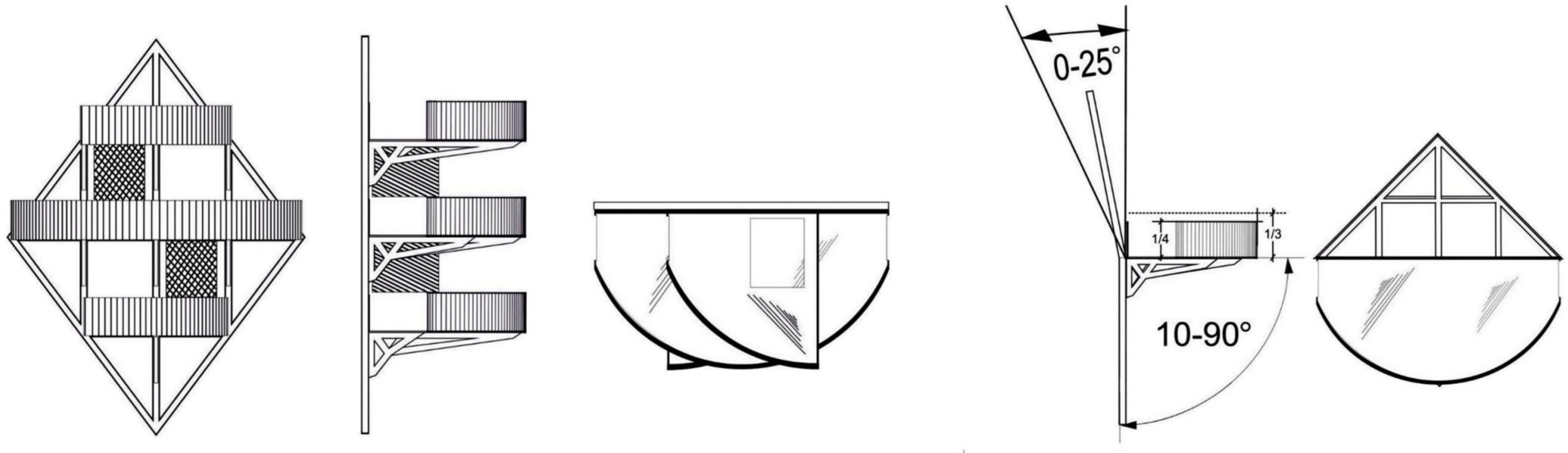
**Empathy Effect:** Because the layered wall structure with vegetation behaves like a living organism, it evokes a sense of empathy and increased responsibility for the shared environment among residents.

**Confirmed Acceptance:** Experiences with prototypes (e.g., Wrocław’s "The Infinite Green") confirm a high level of positive reception and the social empathy these solutions inspire among inhabitants.

**In summary**, in the social dimension, the PMS system is not merely a "decoration" but an active structure supporting the processes of democratizing public space and reclaiming it for human biological and relational needs.

The implementation of PMS structures in Southern European regions generates significant social benefits by providing thermal comfort during the **siesta**. This solution is particularly attractive for Spanish cities, where the break occurs between 1:30 PM and 4:30 PM, and professional activity often concludes only around 9:00 PM. Beyond technical and functional aspects, the social perception of the system remains a key area of research; planned sociological analyses aim to capture the positive impact of green architecture on local cultural customs.

## Selected elements of the panel-module system of a layered wall – PMS according to the solution US 12239064




**Example of a module with three panels on the flat frame in a diamond shape and with one panel on the bent frame.**

# Projections of the panel and the entire module with plants of PMS

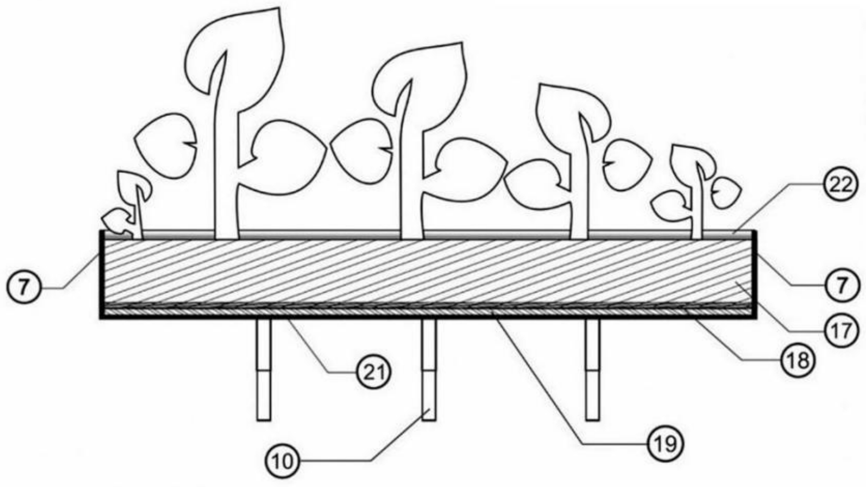



Fig.29

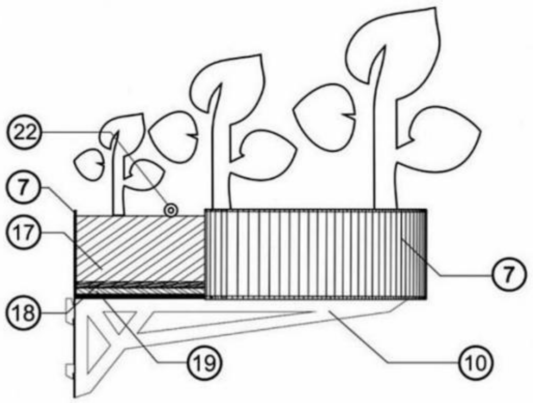



Fig.30

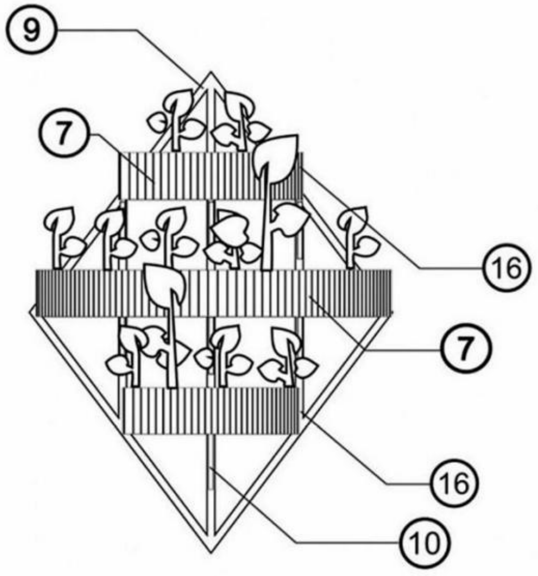



Fig.31

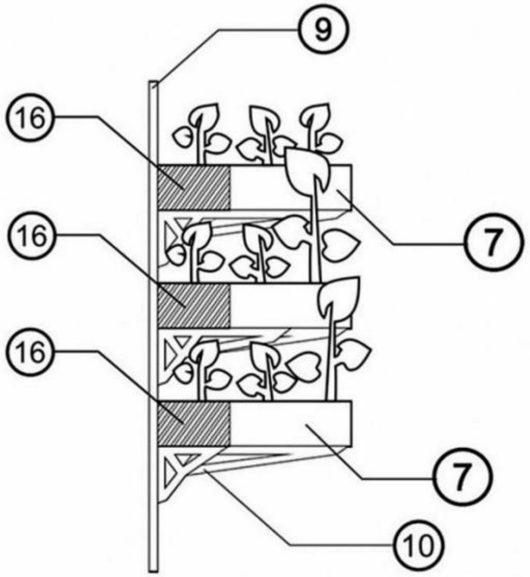



Fig.32

## 1.Variant of a flat vertical wall of PMS

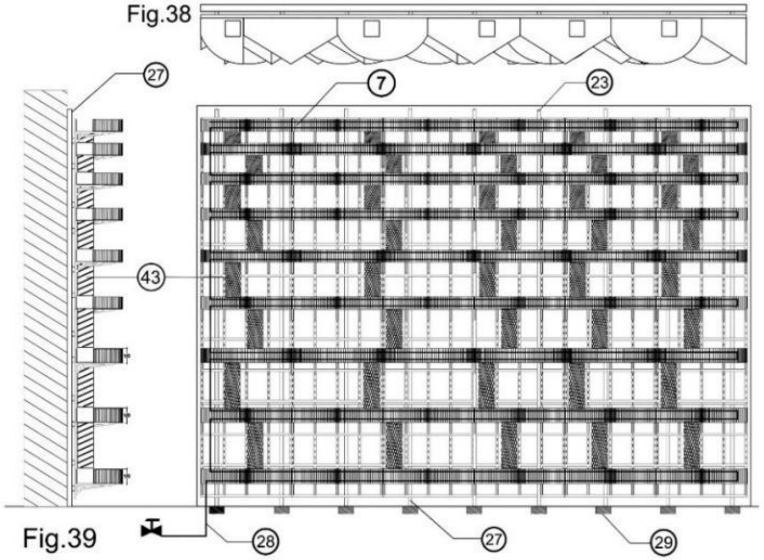



Fig.38

Fig.39

Fig.40

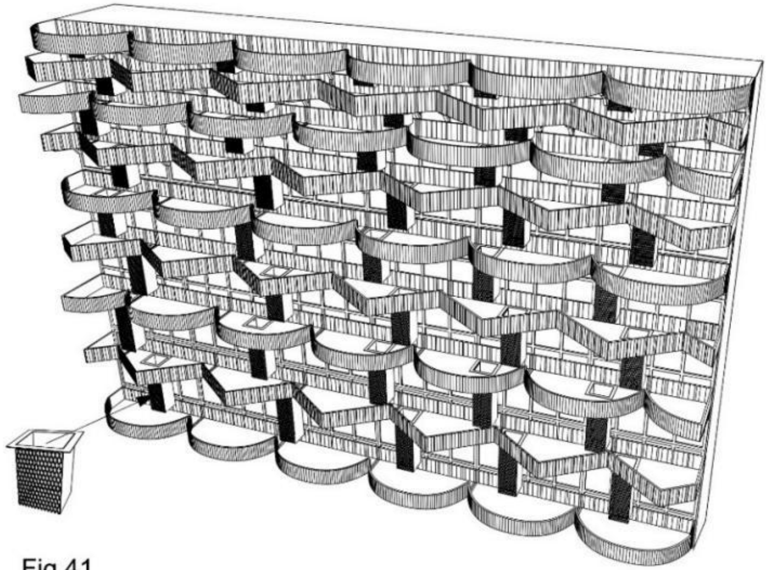


Fig.41

## 2. Variant of a flat sloped wall of PMS

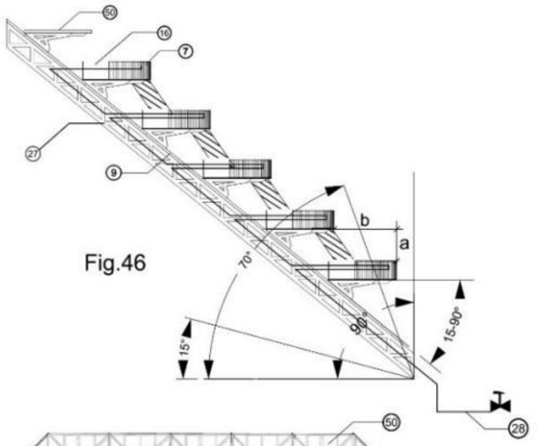



Fig.46

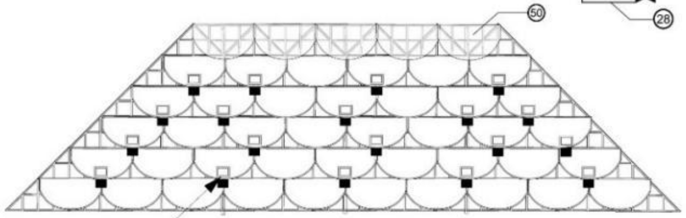



Fig.47

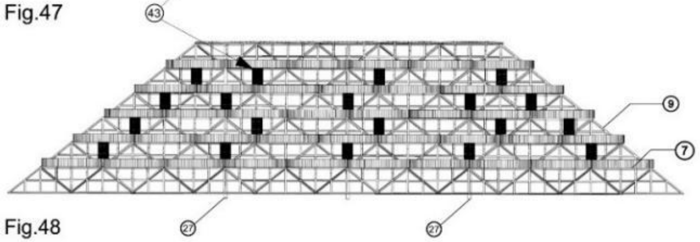



Fig.48

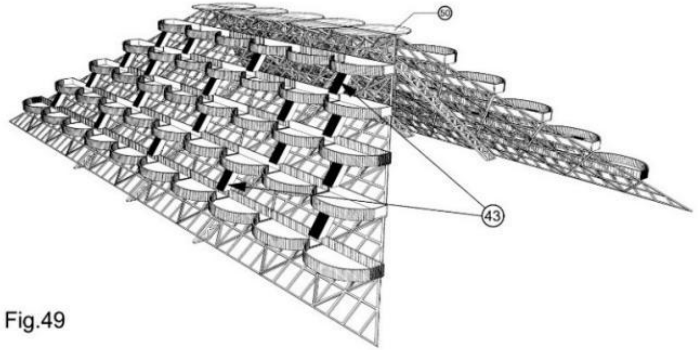



Fig.49

# PMS - vertical flat wall, visualization.

Visible silos connecting layers made of connected single panels

# 3.Variant of the arched-barrel wall of PMS

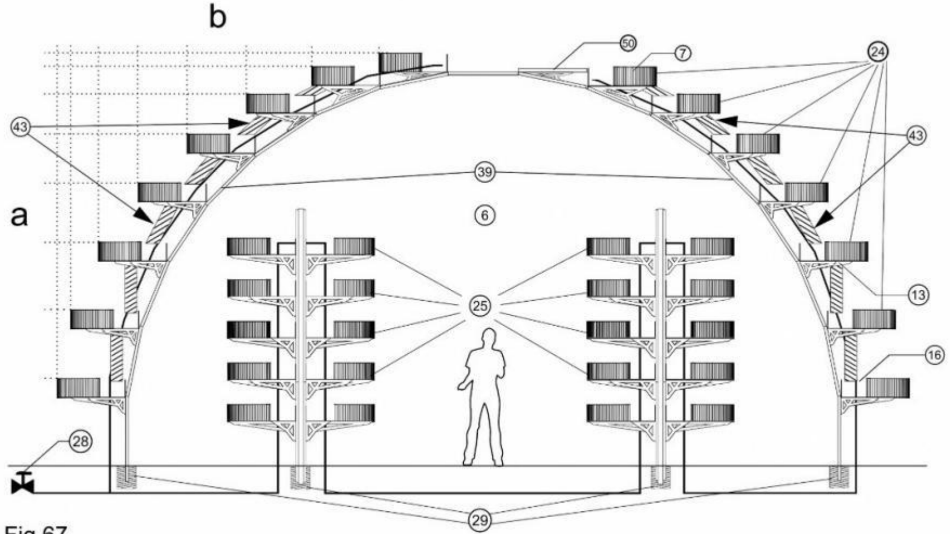



Fig.67

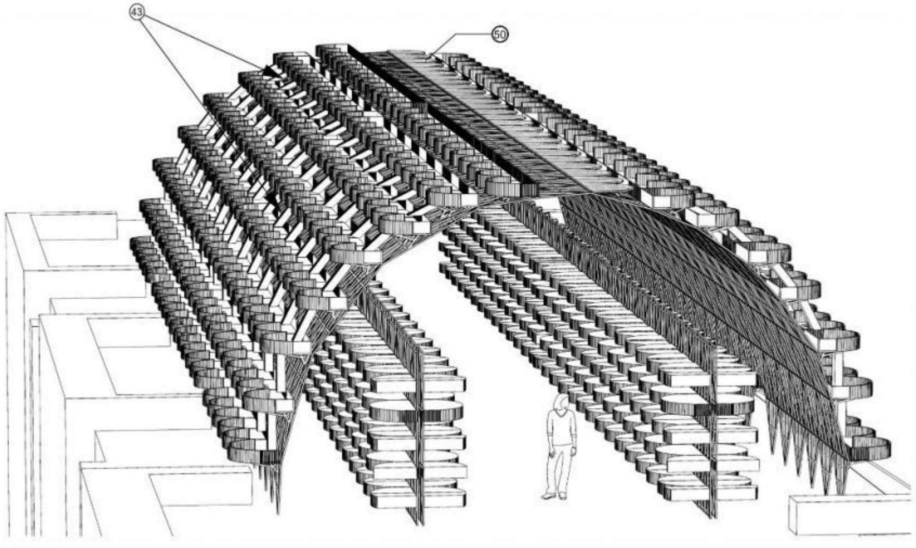



Fig.68

# 4.Variant of the spherical wall of PMS

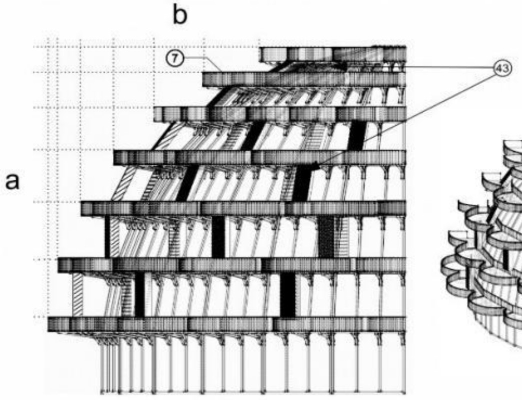



Fig.73

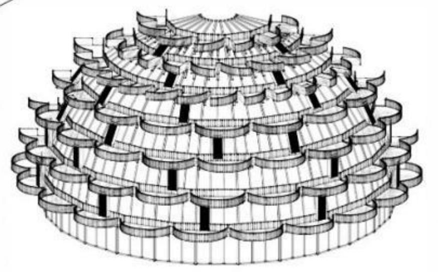


Fig.74

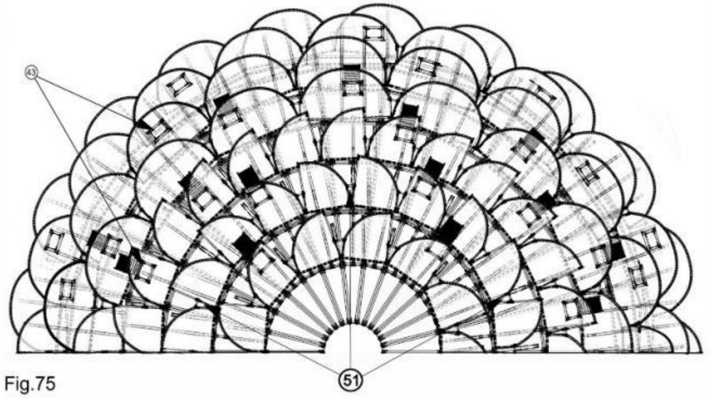



Fig.75

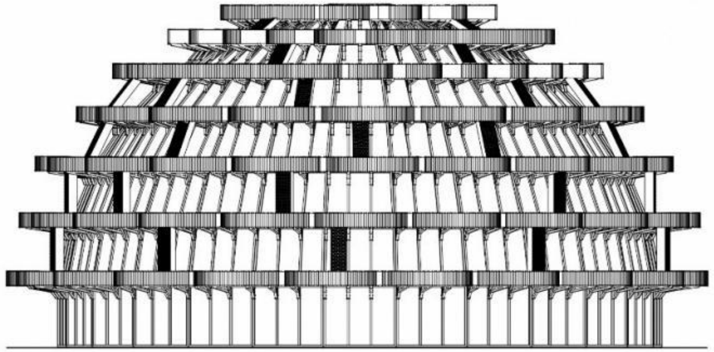


Fig.76

## 5.Variant of cylindrical wall of PMS

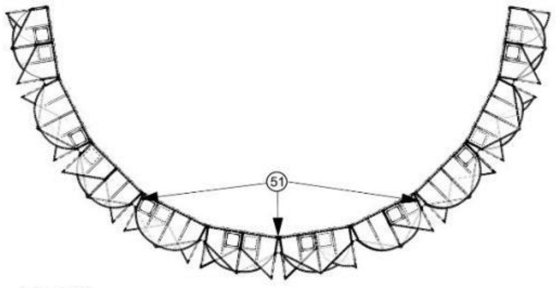



Fig.77

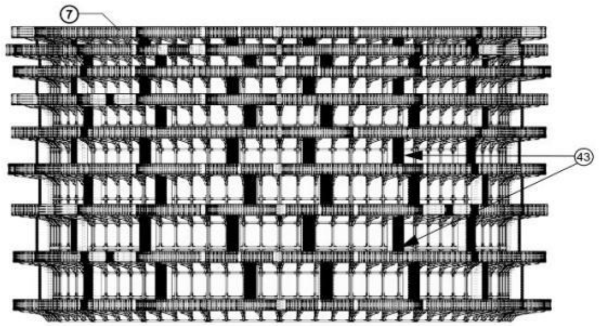



Fig.78

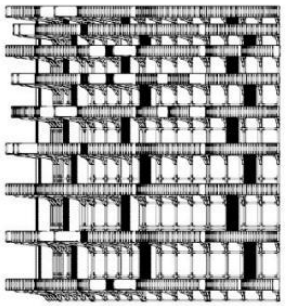


Fig.79

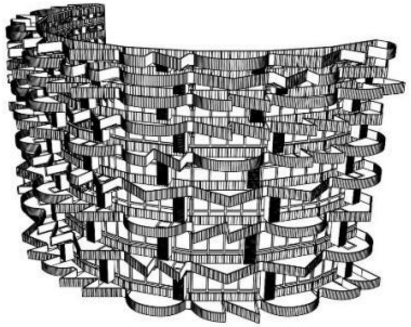


Fig.80

## 6.Variant of inclined - cylindrical wall of PMS

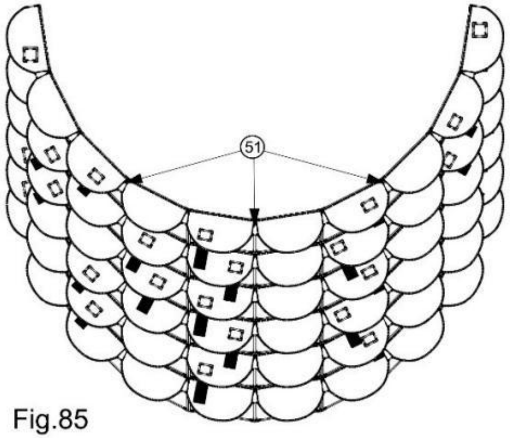



Fig.85

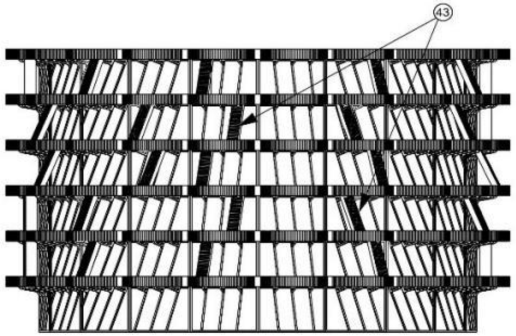



Fig.86

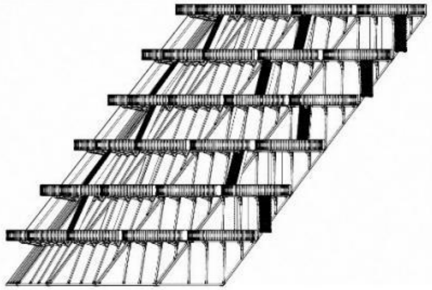


Fig.87

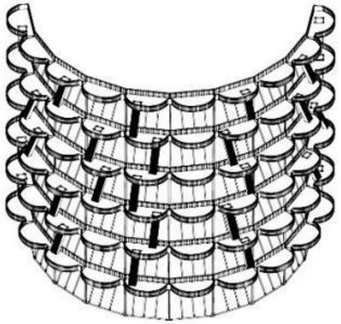


Fig.88

Example of combining four variants of the PMS solution in a single structure: spherical, arch-barrel, flat vertical, and inclined cylindrical variants.

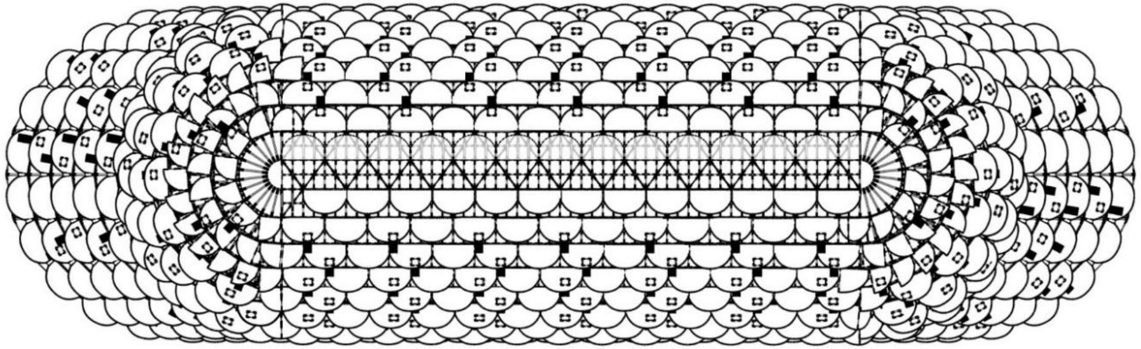


Fig.89

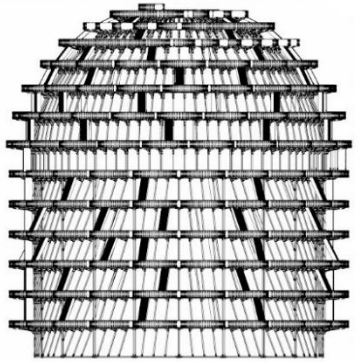


Fig.91

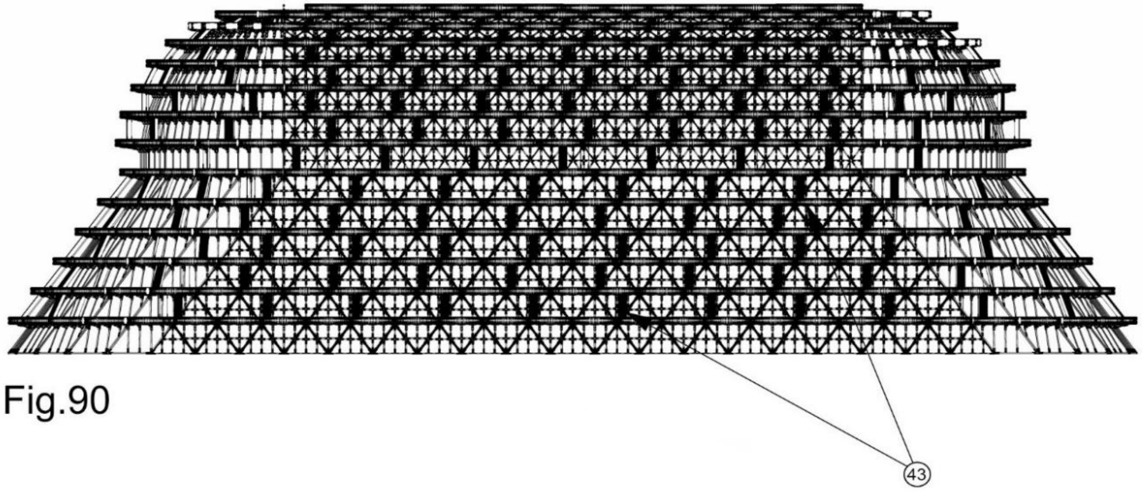



Fig.90

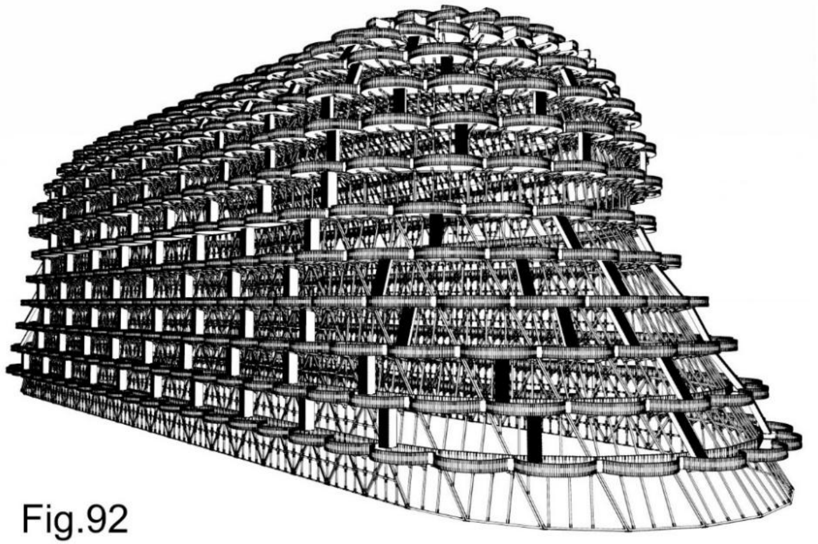
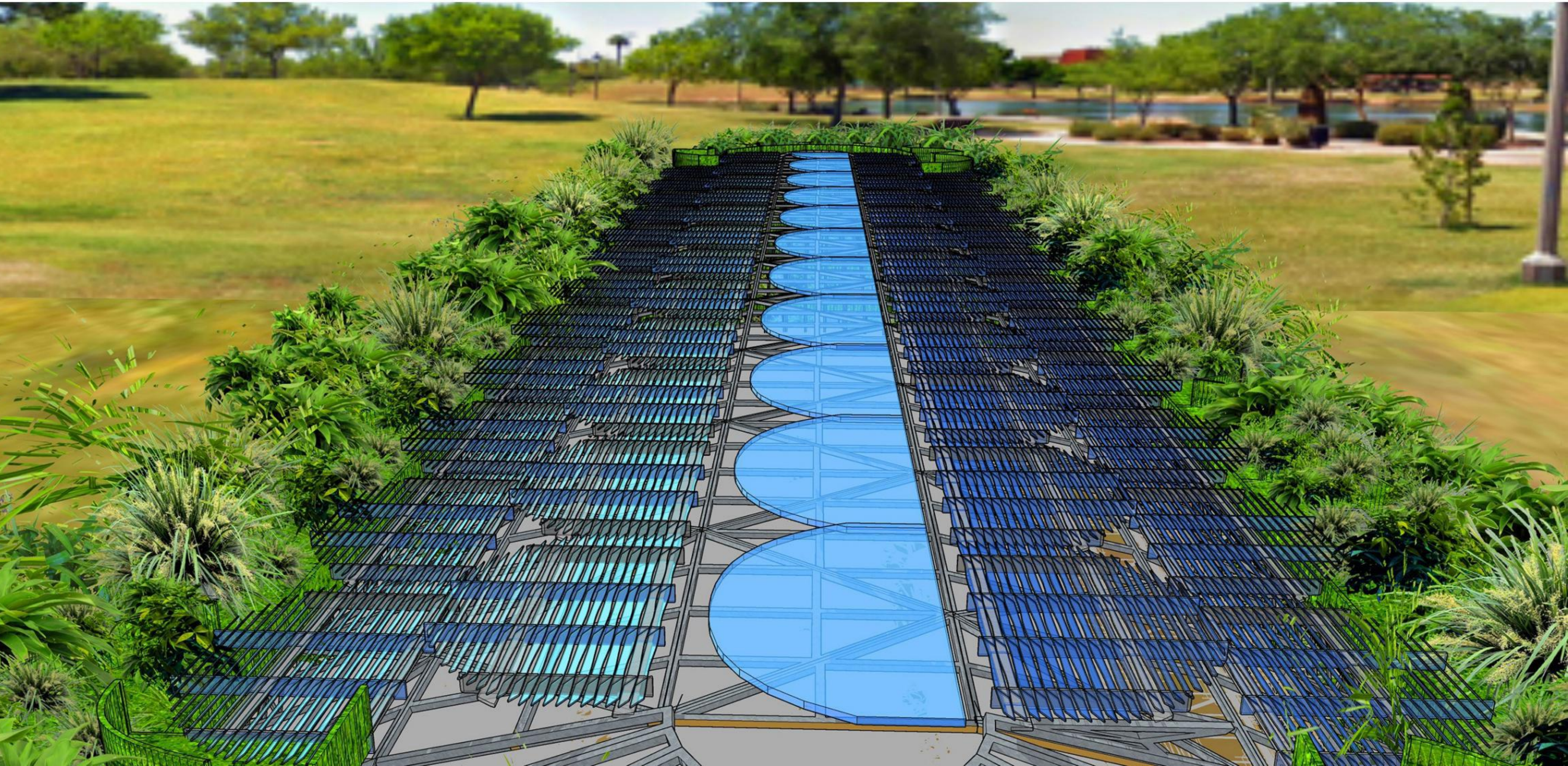


Fig.92

2. The second solution is the Panel-layered system for thermal insulation of a shaded surface, which is advantageously used in synergy with the 1. Panel-modular layered wall system. The solution provides wide possibilities for personalization in terms of shaping the external form and can be developed for use in other applications. It is the subject of a patent application filed with the UPRP (P.437721) in 2021, as well as with the EPO and USPTO. The patent was granted by the EPO (EP22169747) in 2025 and by the USPTO (US 12,595,660) in 2026.

Application of the **patent *EP22169747* in the form of skylights** installed at the top of the **PMS structure,** to provide daylight while blocking the transfer of infrared radiation into the interior of the structure.



**Solution Overview**

The solution consists of transparent layers mounted on a load-bearing structure, utilizing either a photochromic effect combined with a solar radiation reflection function, or exclusively the solar radiation reflection function. The subject of this development is a layered shading system designed to significantly reduce solar radiation transmission into a shaded space. The primary objective of the solution is to provide high-efficiency thermal insulation while maintaining intensive natural sunlight illumination for a shaded flat surface or a three-dimensional space via the use of blinds. Furthermore, it serves as a basis for modeling transparent utility objects in construction and architecture where balancing both of these parameters is essential.

**Technical Specifications**

Constructed from transparent plastic on a load-bearing structure, the system operates through:

The photochromic effect paired with a solar radiation reflection function, or

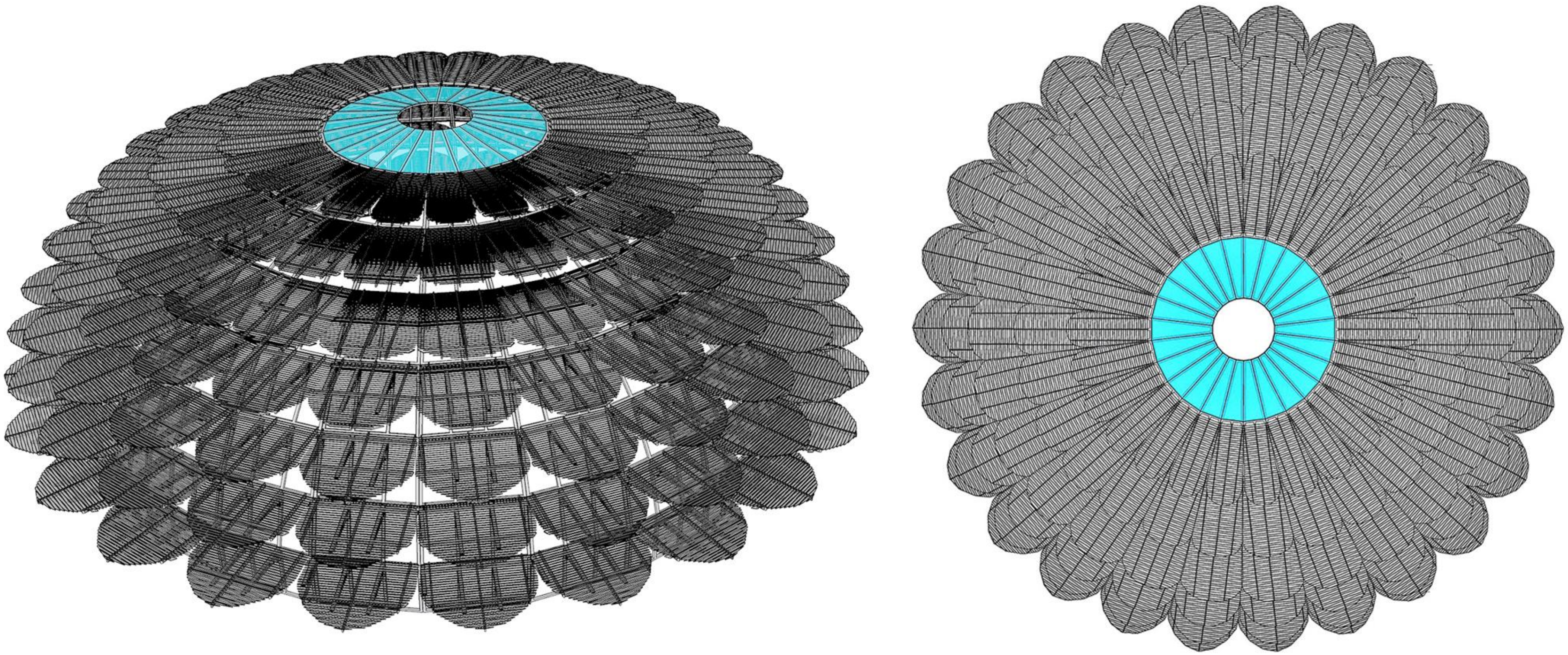
Exclusively the applied solar radiation reflection function.

**Structural Variants of Lamellae**

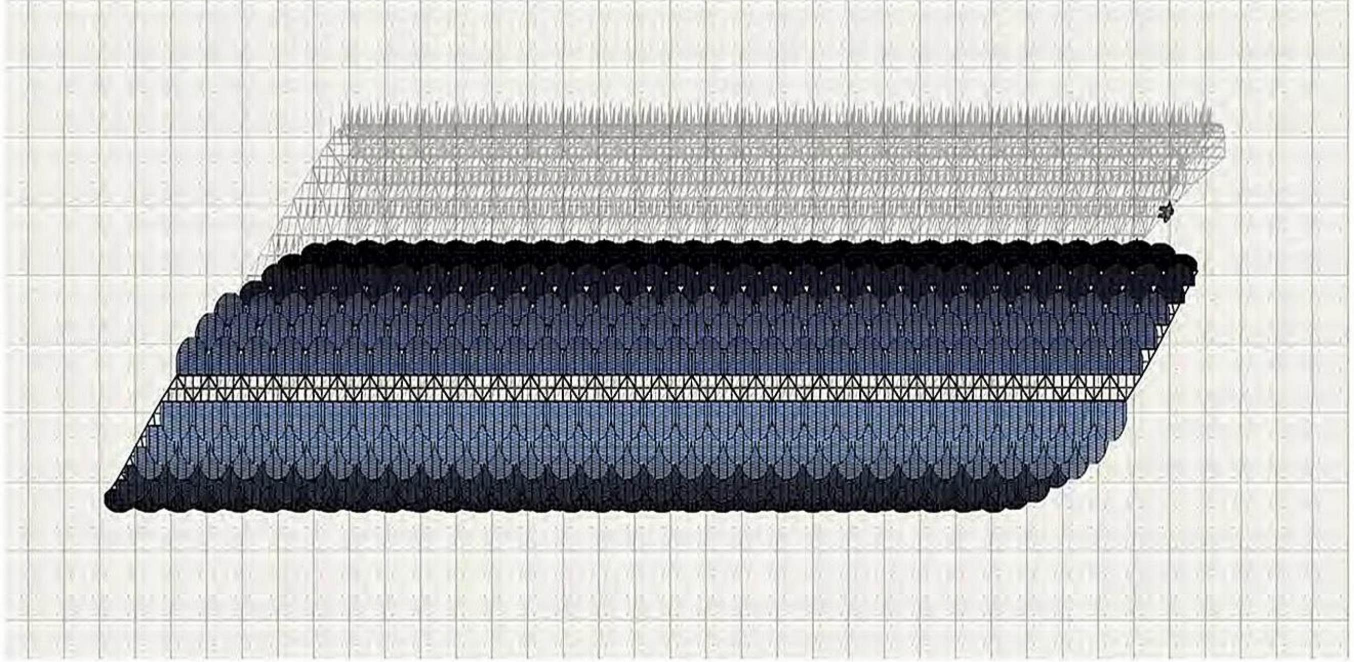
Examples of the shading system configurations utilizing lamellae include:

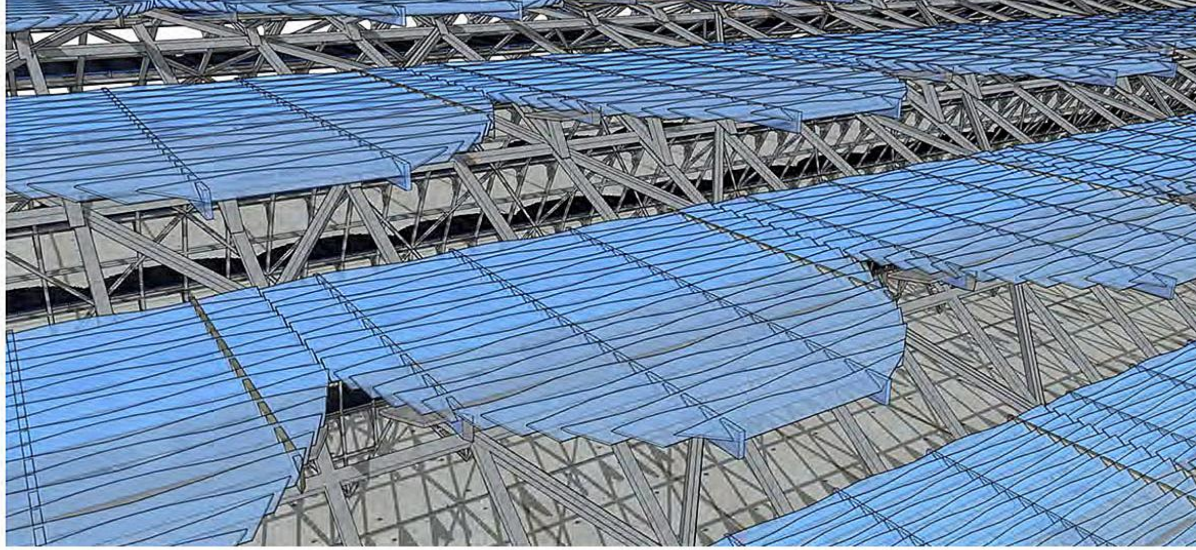
**Wave-form geometry:** Lamellae designed with a wave-shaped side edge to optimize light diffusion and aesthetics.

**Micro-lamellae integration:** Lamellae featuring applied micro-lamellae to enhance selective radiation reflection and thermal control.

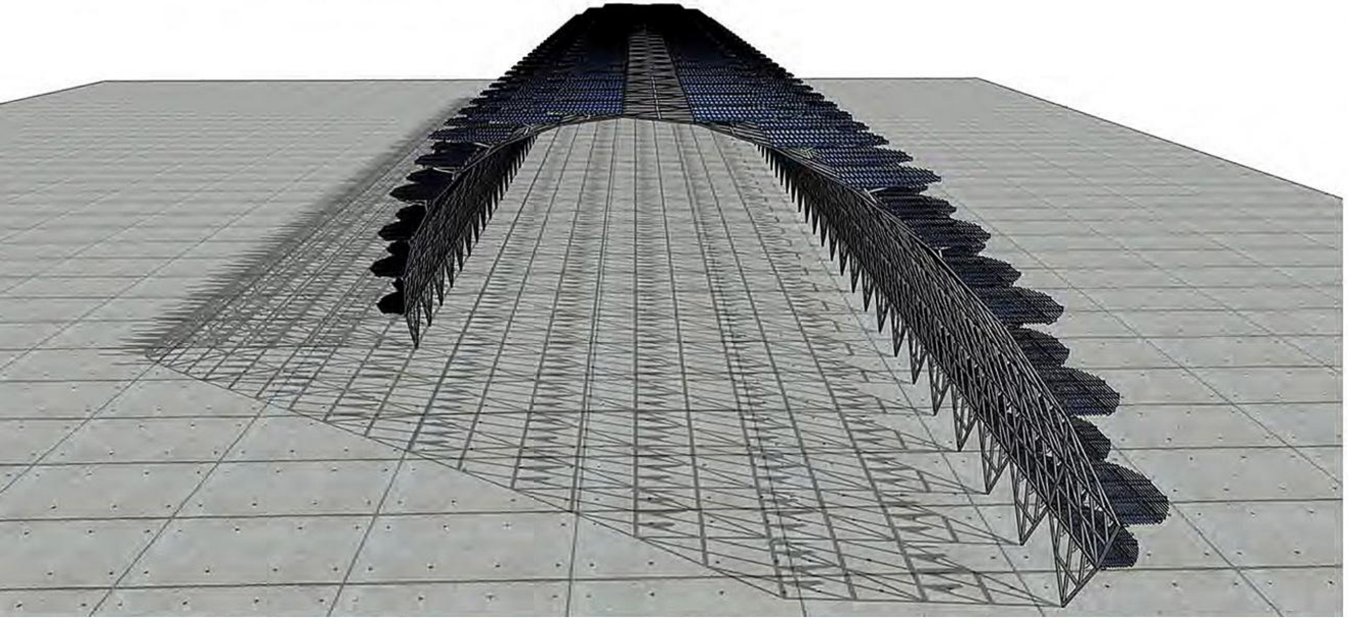


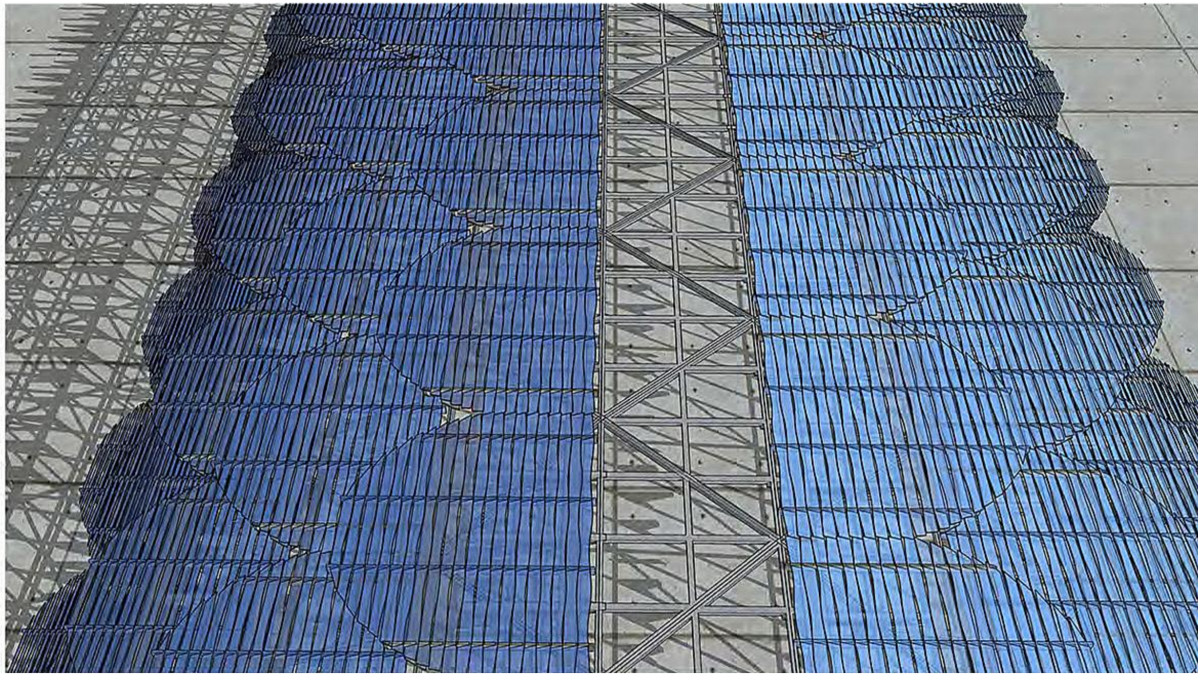
Example of a spherical structure fully covered with panels using transparent shaped lamellae according to solution (P.437721) EP22169747. Transparent photovoltaic panels are visible at the top of the structure. Perspective view - left, top view - right.





Visible panels with transparent lamellae arranged alternately on an arch-barrel structure





Panel-layered system (P.437721), EP22169747, for shading public spaces in cities to provide climate comfort while simultaneously ensuring intense illumination of the structure's interior.

With the widespread implementation of the PMS solution in urban spaces, a noticeable synergistic effect would emerge across various aspects of application:

1. **Environmental, 2. Spatial, 3. Functional-utility, 4. Social, 5. Cultural, 6. Economic.**

**1. Environmental**

Layered wall structures can significantly increase the proportion of biologically active surfaces in urbanized spaces completely devoid of greenery, thereby supporting positive microclimatic changes. These changes involve increasing biodiversity in the urban environment by creating and maintaining organically active surfaces that absorb $CO_2$ and provide protection against dust and noise. The layered wall structure will contribute to rainwater retention in urban environments characterized by a high volume of hardened surfaces, which typically results in rapid rainwater runoff into the sewage system.

Layered wall structures allow a significantly larger area of living greenery to be placed within the small footprint they occupy. By absorbing $CO_2$ and utilizing a substantial surface area of plant matter, they ensure the capture of airborne micro-particles, especially when utilized as barriers separating car traffic lanes from pedestrian paths. Optimizing the irrigation system for efficiency and water conservation, including the use of rainwater for irrigation, can be a vital component of environmental resource management.

Implementing this solution will introduce plant species into the urban space that can serve as shelter and a food source for insects, small vertebrates, and birds living in the urban environment, thus increasing urban biodiversity. Expanding the area of vegetating vegetation in cities through the use of the $CO_2$-absorbing layered wall system will reduce the carbon footprint and limit the formation of urban heat islands.

**2. In the spatial aspect**, the functional and utility features of the solution combine with the beneficial microclimatic effect it brings and the fact that it is possible to flexibly integrate the layered wall structure into existing buildings or create a completely unique and independent architectural structure. This creates added value with a positive integrating effect, enhancing the potential and attractiveness of the space in which it is located.

**3. Layered wall structures** are spaces that promote the health of city residents. On an appropriate scale, they will positively affect the immediate surroundings by creating a microclimate through oxygen production and increased air humidity, reducing the daily temperature amplitude, and providing protection against the residues of burned hydrocarbons and micro-dust, as well as reducing noise in the city—for example, by separating car traffic lanes from pedestrian paths or surrounding sensitive areas where young children spend time, such as playgrounds (Jordan gardens) or parks.

The solution meets the forecasted trend of dynamic development of the world's large metropolises, which may double in size over the next 40 years. Therefore, a second key function of the solution is the possibility of its application for plant production within the spatial constraints of the modern city—which occupies an ever-increasing area with a dynamically growing population—or for conducting cultivation in steppe or even desert conditions of hot and dry climates

**4. The layered wall structure**, which contains an element of vegetating vegetation and thus functions like a living organism, can trigger an empathy effect among city residents and a sense of responsibility. In the social aspect, the psychological effect accompanying community gardens created in city centers—where biologically active surfaces are scarce, car traffic and often commerce are being displaced, and where high levels of alienation and anonymity exist among residents—is invaluable. Experiences with the prototype of this solution in public space in Wrocław (from 2015 to the present) decisively confirm the positive social empathy it evokes in residents. The educational effect is also significant; the layered wall structure serves as a social laboratory and an open botanical garden for the urban resident, where dozens of species and subspecies of plants, including numerous herbs and other utility plants, can be utilized within a single, even small-scale object.

**5. As a systemic solution**, it offers a wide range of possibilities for designers to apply in various forms and scales depending on the specific needs of an urban space. This is crucial due to the cultural aspects of cities, particularly in Europe, which have been shaped over centuries or millennia and are characterized by rich, diverse architectural environments that influence the design of new structures, especially those aligned with EU climate policy.

**6.** Since the solution consists of roughly a dozen elements, it is relatively uncomplicated and therefore easy to manufacture, assemble, or disassemble using various materials. It would be inexpensive to produce even in small series, and even more so in mass production, which would positively impact the economy of the region or country if the system were popularized.

The popularization of the modular system could influence the increase in plant matter production, particularly for species that adapt well within the solution in a given climatic region. The modularity of the system makes it easy to calculate the costs of its components as well as production and assembly across different countries. Due to its durability and ease of assembly and disassembly, the solution may create a secondary market for its components.

**PANEL-MODULAR LAYERED WALL SYSTEM**

The subject of the proposed solution is a panel-modular layered wall system used to shape spatial structures that provide climate comfort to users. It is characterized by oxygenated, purified (from micro-dust), cooled, and humidified air, and can also serve plant production in challenging urban spatial and/or climatic conditions. The system integrates various load-bearing surfaces—flat vertical, inclined, arch-barrel, spherical, cylindrical, and inclined cylindrical—obtaining a substantial horizontal surface for plant vegetation. This takes the form of layers created from side-joined panels connected by vertical silos filled with substrate. The front shape is appropriately optimized for lighting, rainwater harvesting, and plant vegetation, using a suitable substrate combined with water and mineral plant nutrition, which provides significant independence from the environment in which the system is installed.

The panel surfaces are planted according to the bipolar planting rule, utilizing either transparent or opaque panels. These are mounted on supports with a variable angle to ensure an always horizontal panel arrangement. Panels are placed in groups of no more than three when containing plants, and potentially in larger quantities when without plants. They are mounted on a flat or curved module frame in the shape of a rhombus, rectangle, or trapezoid, made of a closed profile with a rectangular cross-section. The module frames are connected to each other along the perimeter using connectors, enabling fast assembly and disassembly of the load-bearing structure.

A set of six variants of the solution enables the configuration of eco-architectural objects with diverse forms, where the form and function of the object are strictly intertwined.

**Innovation and advantages of the panel-modular layered wall system**

**1.1.** By utilizing the six variants of the solution—vertical flat, inclined flat, arch-barrel, spherical, cylindrical, and inclined cylindrical layered wall structural elements—we can construct structures in open, semi-closed, and closed configurations, with or without a supporting frame. The result is an autonomous, self-supporting object that provides climate comfort or serves plant production in challenging spatial and climatic conditions. In contrast, existing "Green Wall" solutions are practically limited to the plane of a building's facade. These six variants allow for the generation of eco-architectural objects of various forms where form and function are tightly integrated; this is a crucial feature, especially for implementation within existing urban spaces.

**1.2.** The solution ensures climate comfort, particularly within closed and semi-closed structures, and can have a measurable impact on the urban environment's climate. Exemplary closed structures can be particularly useful for achieving thermal comfort in areas with high solar exposure—such as Southern Europe during summer, in temperate climates, as well as in hot and dry regions—without the need for active cooling via air conditioning systems. Reducing the temperature by approximately **5–7°C** and increasing humidity by about **20–30%** represents a significant microclimatic gain for the user, especially in public urban spaces when applied, for example, in the form of "green tunnels" for pedestrian transit.

The impact of such structures on the climate of the immediate urban environment is of paramount importance, offering potential improvements in air quality through dust filtration and humidification, temperature reduction, and the subsequent reduction of greenhouse gases. The second key function of the solution is its applicability for plant production in unfavorable conditions, such as in cities or in semi-desert and desert environments. The optimization of light exposure for panels connected in both horizontal layers and vertical silos, a sufficiently thick and mineral-saturated substrate layer, and the utilization of rainwater alongside constant irrigation are key assets that allow for efficient vegetation (plant production) in urbanized spaces entirely devoid of biologically active surfaces. The various functions provided by the solution are cumulative. The microclimatic features provided by this compact structure enable plant production in unfavorable semi-desert and desert conditions with a relatively low investment of energy and resources, where water is the only scarce element, and both plants and people are the beneficiaries.

**1.3.** The layered wall solution, by combining two variables—the horizontal and the vertical—represents a fusion of their functionalities, as it allows for shaping in both dimensions to fully achieve the intended goals.

**In the vertical direction**, the system allows for variably optimal regulation of the spacing between layers to accommodate different types of vegetation or plant sizes. By connecting horizontal layers with vertical silos filled with substrate, the system realizes three objectives:

> **A) Free moisture transfer** throughout the entire layered wall structure. Rainwater supplements the irrigation system, and it can be assumed that the irrigation may be deactivated during heavy rainfall, as moisture transfers naturally from the upper levels—which collect the most precipitation—to the lower levels of the structure.
>
> **B) It enables the transfer of microorganisms** throughout the entire structure.
>
> **C) Unhindered expansion of root systems.** Silos can be used to connect all or selected layers of the structure.

**In the horizontal direction**, the configuration of the structure's layers involves the appropriate arrangement of the six basic panels of various shapes and sizes, along with supplementary shapes, to optimize surface lighting and rainwater harvesting, and to accommodate the specific type of plant matter applied to the panels.

**1.4.** The solution is characterized by a **horizontal layered arrangement**, which enables natural plant growth, in contrast to "Green Wall" solutions where plants are typically planted parallel, at an angle of approximately 45 degrees, or perpendicular to the ground in small containers.
The combination of panels connected into layers and placed horizontally within a vertical load-bearing structure provides significant advantages for vegetation, particularly regarding the **volume of the substrate**. By joining panels into long continuous layers with varied edges, placed one above the other, favorable conditions are created for plants growing within the constraints of the layered structure. The substantial ecosystem formed by each individual level (with panels overlapping by more than one-third of their depth) allows plants to engage in **collective vegetation**. This leads to an increased root system mass, better moisture retention, and consequently, greater resistance to drying out or freezing in winter compared to standard Green Wall solutions, where plants in temperate climates often fail to survive the winter without root system heating.
The arrangement of horizontal layers is further reinforced by **vertical silos** filled with substrate that connect them. The substrate thickness depends on the spacing between layers—which can vary within a single structure or relative to the scale of the object—ranging from approximately **15 cm to 35 cm or more**. Because the substrate spans the entire level of the panel layer, the **rooting zone** is significantly larger than in the separate containers used in traditional Green Walls. This allows the root system to expand both horizontally and vertically through the vertical silos.
Structures utilizing this system will be massive with a **high plant volume**, achieving a climate comfort effect that has a measurable impact on the surrounding environment. Therefore, it serves as an effective tool for mitigating **urban heat islands**.
Furthermore, it is possible to **differentiate the substrate** on each layer, tailoring it to specific plant requirements or regulating the moisture of each layer individually (or groups of layers connected by silos). This allows for a high diversity of plant species, including succulents, perennials, grasses, ferns, shrubs, and selected geophytes. Another advantage is the ability to use plants of varying sizes; consequently, the total plant mass of these "layer-ecosystems" as a whole will be significantly greater than in known Green Wall solutions.

**1.5.** This panel-modular system allows for a relatively small footprint—occupied by vertical, inclined, arch-barrel, spherical, cylindrical, or inclined cylindrical structures—to achieve a **living volume of vegetating vegetation multiplied several-fold**. This is particularly valuable in densely built-up areas where spatial constraints exist and biologically active surfaces are scarce or non-existent. Semi-closed or closed structures utilizing double walls can be especially efficient in this regard. It can be estimated that **1 m² of base area** occupied by a vertical structure can provide approximately **18–22 m² of planting surface** (with a wall height of about 12 m, yielding 18–22 layers), or even more depending on the total height. Due to their compact design, these structures will also remain effective in hot and dry climates.

**1.6.** The system employs the principle of **bipolar plant placement** on the panels, relative to the light intensity reaching the panel surfaces within the structure. On average, the three panels mounted within a single module are planted with a specific set of perennial plants according to this bipolar rule.

**1.7.** The **variation in layer edges** within the layered wall structure—resulting from the assembly of panels in two basic shapes—is designed to optimize sunlight exposure for all panels within a given module, utilizing both direct and reflected light. Furthermore, this design facilitates **rainwater harvesting** to supplement the irrigation system. This configuration allows certain plants to grow beyond the fixed distance between the top of the substrate and the bottom of the panel directly above; because the panels do not fully overlap in the vertical plane, the system can accommodate plant species that grow taller than the standard inter-layer spacing.

Existing Green Wall systems are limited to a uniform, vertical plane from which plants grow, or to a system of separate plant containers where water is supplied exclusively via an irrigation system. The proposed system also provides for the **scattering of reflected sound waves**.

The wall surface can be designed based on intended application or aesthetics, allowing for either a **homogeneous or heterogeneous surface shape** by combining appropriate panels. To achieve a design using only large panels with a uniform semicircular or triangular shape across all layers—aside from centrally placed large panels located in the middle of a module—two half-panels can be joined into large semicircles or interspersed with triangular panels. By interspersing large and small panels, one can achieve either an orderly front plane or an intentional visual "chaos," which may serve a functional justification. The freedom to shape structures using this system—due to the ability to match panel shapes and apply a wide variety of plant life—ensures that aesthetics, as a derivative of the structure, remains in fusion with its functionality, mirroring the natural plant world.

The varied surface of the structure's plane allows for the **scattering of sunlight**; consequently, reflected light provides illumination for plants located in the background of individual panels, especially those positioned deeper, such as near a building facade. Similarly, rainwater is captured by various sections of the panel surfaces forming a given layer. This is sufficient because the moisture obtained in this way spreads throughout the connected substrate of that layer, or across multiple layers when they are connected by **vertical silos**.

Thus, **lower water consumption** is possible thanks to the horizontal, partially overlapping layers of the structure, where plants benefit from atmospheric precipitation alongside the irrigation system. Excess rainwater flows to lower levels through drains located in the connection strips and through the silos.

**1.8.** Layered wall structures can function as a **vertical garden** with a substantial acreage for plant production in cities lacking biologically active surfaces, or in hot and dry climate regions where such activity is limited and naturally difficult. Crucially, the system supports **year-round production** in both types of climates.

Inclined or arched structures can be installed on flat rooftops in cities to serve as **community gardens** and/or to provide climatic and decorative functions. Within these, vertical structural elements for plant production can also be integrated. In such cases, the external structure acts as a shield against urban pollution, as well as minimum low or extreme high temperature fluctuations. When mounted on a building wall, the solution does not interfere with the facade, except for the necessary installation of a mounting rack for the module system, which can be individually tailored to specific requirements. Depending on the needs, the rack can be mounted directly to the facade or onto load-bearing pillars anchored in the ground.

**1.9.** It is possible to design **large-scale structures** using the six variants of the solution. These can be free-standing and self-supporting, utilizing rhombus-shaped frames—particularly in arched or spherical variants—due to the high structural strength of this design. By using appropriate profile cross-sections for the module frames, the structures can support the substantial additional load of panels filled with substrate and plants.

**1.10.** The panel-modular solution—in its vertical, flat inclined, arch-barrel, spherical, cylindrical, and inclined cylindrical versions—allows for the **combination of elements from all six variants into a single target structure**. It is possible to use various system elements, such as square/rectangular, trapezoidal, or rhombus-shaped frames, within one project. Furthermore, the free arrangement of panels on the modules offers numerous possibilities regarding both the intended purpose and the final form of the structure.
In arch-barrel or spherical structures, the distances between the surfaces of subsequent layers increase from top to bottom (where light intensity on panel surfaces is slightly lower), and the gaps (clearances) between the front edges of the panels increase toward the top of the construction.

This creates **exceptionally favorable conditions for plant vegetation** on panels located both directly on and inside the structure when combined with vertical or inclined flat walls. The inclined cylindrical structure offers similar functionality due to the only partial overlap of the panels. The functions of these structures—utility, climatic, as public spaces, or as production units for plant cultivation—merge within any configuration. This makes them highly effective for growing metropolises by addressing the broader socio-spatial-climatic context.

**1.11.** Using the load-bearing construction applied in vertical, inclined, arch-barrel, spherical, cylindrical, and inclined cylindrical layered wall structures, it is possible to utilize panels devoid of vegetation throughout the entire structure. These can be transparent (with appropriate coatings) or solid, to achieve the two primary goals of the solution across diverse spatial and climatic environments.

**1.12.** To enable the partial or complete replacement of panels at any level of the layered wall structure, the panels are equipped with underside **docking strips** that engage with the **support guides**. After removing the lock and cutting through the root system of the substrate within the panel (symmetrically on both sides to the depth of the connecting edges), an individual panel—including its substrate and plants—can be quickly removed from a layer using a lift. This is done without dismantling the supports located in the frame's mounting holes. Such root cutting is necessary for certain plant species; in the case of replacing the contents of one or more layers, this mechanism significantly facilitates the process, which can then be completed at ground level.

**1.13.** A crucial element of the PMS solution is the **skylights** located in the apex of closed or semi-closed structures. These integrate a second, complementary patented solution presented in this study: the **Panel-layered system for thermal insulation of shaded surfaces**. Its primary function is to deliver the maximum amount of light required for the vegetation on the interior parts of the layers while simultaneously blocking infrared radiation from entering the structure's interior.