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BIOLUMINESCENT PAVILION:

Temporary Architecture Provides Lighting

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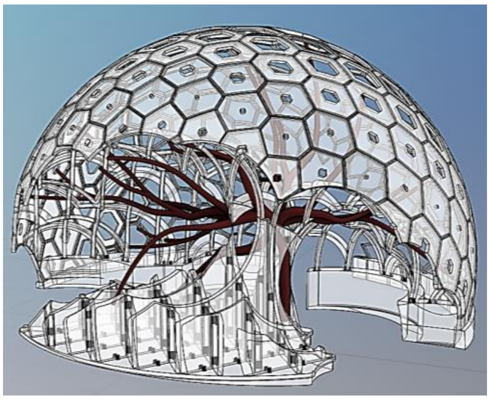

Bioluminescent Pavilion

PART 1: PROPOSITION

ABSTRACT.

The present study will evolve around the design of a pavilion located at key points in the Aberdeen city. The structure will provide low intensity lighting using bioluminescent organisms on its inner and outer surface. For the creation of the design, computational design techniques will be employed, based on mesh sphere geometries, honeycomb patterns and organic forms of root system. By defining parameters and relations, we can design in a flexible environment that allows us to test several form options in a fraction of time compared to the traditional design approach.

KEYWORDS

Pavilion, Bioluminescent, Light, Bio-mimic, Computation Design, Porous Architecture

1. INTRODUCTION (HEADING 1)

As the title foretells, this study combines the fields of architecture and biology. Specifically, following advanced architectural design methods, the final design is reached achieving structural sustainability and architectural interest. Features of porous architecture have been employed in functional building aspects such as circulation and filtration with respect to the external environment.

Biological interest is expressed a) indirectly, through the bio-mimetic architecture, which has a visual impact as it is applied to the dome of the construction in the form of a honeycomb pattern, and b) directly, as living organisms (fungi) are applied to the structure in order to provide light during the night times.

The association of crime/ security and lighting has been extensively shown in previous studies. Demographic qualitative studies have associated the feeling of safety when walking alone in a local area after dark and how this impacts the human behaviour.

Special mention is made not only to the living organisms that after genetic manipulation, acquire properties of luminance and eventually emit light, but also to an innovative material which is used in luminescence technology, that provides materials, especially concrete, technical and decorative properties in terms of design.

Three computational design methods are employed and analyse the overall form definition process, the dome and the non-structural decorative element of a root system.

2. CASE STUDIES

The following tables list the eleven characteristics that define whether a design is considered porous according to Steven Holl and follows the second table which analyse 9 case studies. Nine buildings were studied which meet the requirements to be characterized as porous structures in terms of their visual effect. The existence of small or large openings, passages that allow matter to pass through, extend your view unrestrictedly or pass the viewer from the one environment to the other.

Table 1 Primary definition of the design concept of porosity by Steven Holl Architects, New York.

Porosity	
Porous, Permeable	Honeycomb
Screen, Net	Riddle, Sponge
Pore	Opening, Hole
Aperture, Passageway	Cribiformity
Sieve-like, Sieve	Pervious
Unrestricted	

Table 2 Case studies.

Case Studies			
No	Project	Type of Porosity	Strategy
1	Simmons Hall by Steven Holl - Cambridge, Massachusetts - 2002	Porous, Sponge form, Screen/Net, Openings	Have been followed at least 4 parametric rule schemata.
2	Sliced Porosity Block by Steven Holl - Chengdu, China - 2012	Porous, Sieve, Openings	Sun sliced geometry
3	RED7 by MVRVD - Moscow, Russia - 2022	Porous, Openings	Modular sculptured volume, inspired by Minecraft game, various windows sizes, distinctive entrances and sloping roofscape.
4	Museum of Natural History Expansion by Jeanne Gang - New York - 2022	Porous, Openings, Pathways	Amorphous openings, tectonic forms, geological processes has been used to form this design.
5	The Zendai Himalayas Centre by Arata Isozaki - Pudong, Shanghai – 2010	Porous, Openings, Pathways	Soft curves of an "organic forest" contained within the hard, symmetrical lines of "crystalline cubes". Large expanses of irregularly shaped holes.
6	Hexelace by Studio Ardete – Mohali, India – 2018	Openings, Honeycomb	Honeycomb pattern flows organically in the facade .
7	Audrey Irma's Pavilion by OMA – Los Angeles, California - 2021	Openings, Honeycomb	Bent walls covered by hexagonal shapes, visual connections that determine outdoor indoor porosity
8	Boolean Operator Pavilion by Marc Fornes - Suzhou Shi, China – 2018	Porous Shell / Openings	Continuous surface grows from a network of columns that peel open into the enclosing shell. Crawling agents of a computational search protocol find their way across the spherical mesh, leaving a trail of non-linear stripes in one pass and apertures between them in another.
9	Porous Manifold by F.A.D.S., Fujiki Studio and KOU::ARC - Tokamachi, Japan – 2018	Porous, Openings	Homogeneous space, create irregularities by the random pattern of the skeleton, holes which are open and close as necessary to communicate with the outside like living things.

3. Biology In Architecture

The concept of organicity in architecture is difficult to clarify and especially to be understood by people who simply observe it. It must be experienced in the natural environment in which each building is located. Organic architecture does not imitate shapes of physical (organic) forms, but contains those mechanisms, which govern the various physical processes.

3.1. Biomimetic or Bio mimic (Biomimetic) architecture

Biomimetic is the imitation of living organisms and ecosystems for creation sustainable design solutions (Sarwate L. P., 2016). The bio-mimetic architecture, considered as a living system of expression, through its creators, it maintains continuity and the interconnection of historical thought with the technology of each era. Examples are the shells of shells (which have a curved, wavy shape, although is very light allows them to withstand enormous pressures), which were the source inspiration of engineers to create dynamic shelters in modern buildings.

The study of the mechanical strength displayed by the individual beehive cells is fascinating (Fig.1). The continuous micro-vibrations from the perpetual motion of their inhabitants, which could be compared to seismic vibrations, so that by detecting the "static amplification" of the cells, an attempt can be made simulation for the seismic study of buildings.

Figure 1. Honeycomb cells.

3.2. Biological Architecture

This notion is defined as architecture that incorporates living elements into the design, usually from the plant kingdom. This results in the ability of a scholar to manage the behaviour of some animals, so as to utilize their natural constructive abilities, guiding them according to the desired genetic programming, in order to "self-construct" and self-organize (Ardavani, 2020).

3.3. Genetic Architecture

Genetic Architecture has been considered as an extension of its philosophical concept. Genesis, channelled through calculations of the development of logical systems, with aim the dissemination and mutation of inheritance information, is actively involved in process of architectural design. (Ardavani, 2020).

Genetic research set the goal for the creation of "living" organisms. In essence, genetic control has led to the growth of living cells, which have been transformed into "building materials" and living spaces, which have been "designed", through genetic manipulation. Furthermore, through digital design and production (CAD / CAM), in the context of genetic engineering, and with the principle of "what can be designed can be built", makes it possible to create self-evolving and self-sustaining organisms, on a scale 1: 1, without the requirement of mass production

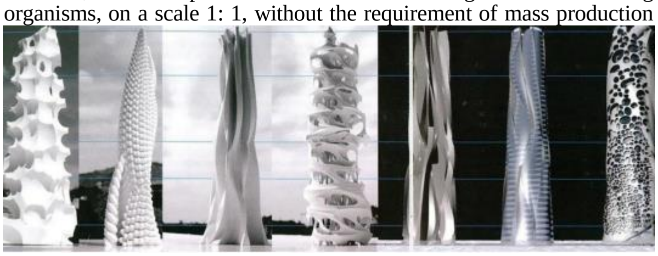

Figure 2. Skyscraper models design and 3D printing for its beach (Estevez T. C., 2009)

3.4. When Porous Architecture Meets Biological Architecture

The reason for referring to these architectural categories with reference to specific terminology (honeycomb), is none other than the intention of this dissertation to mix the two kinds under one project.

The aim is to use features that are recognized in both architectural species such as pathways, openings, honeycomb cells etc in order to have a hybrid model, which with the help of bioengineering (plant bioluminescence) can offer to the human community and the environment, sustainability and facilitation of daily activities.

4. From Conventional Lighting to Alternative

4.1. *Overall association of crime/ security and lighting*

The lighting in the areas tends to prevent criminal behaviour as it increases the probability of arrest of the perpetrator. Data has shown that most criminal acts take place around common commuting hours of 5:00 to 8:00 p.m. With the presence of light, victims have the ability to identify

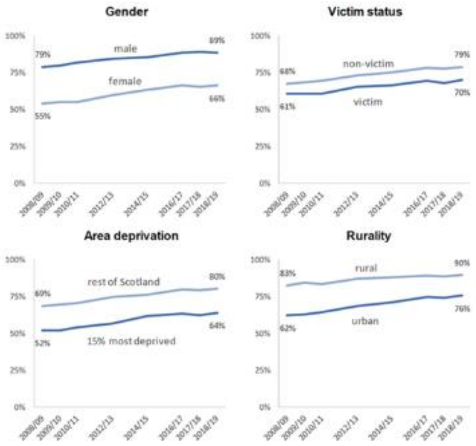

Figure 3. Feeling of safety when walking alone in the local area after dark by demographic and area characteristics, 2008/09 to 2018/19.

the perpetrators or the potential threats. (Calandrillo & Buehler, 2008).

4.2. *Bioluminescence*

Researchers have identified approximately 10,000 species from 800 genera which have the ability to glow in the absence of light. However, as Haddock et al., mention on their research, this may well be an underestimation (Haddock et al. 2010). The reason why organisms emit light is not completely understood. However, the reason why most organisms emit light in the dark is mostly an attempt of communication between similar species, to dissuade predators, attract prey or as part of the courtship behaviour (Ellis and Oakley 2016; Wainwright and Longo 2017; Verdes and Gruber 2017; Labella et al. 2017).

The continuous evolution of bioluminescence has resulted in numerous biochemical solutions for light generation. Thus, proving that the ability of organisms to emit light for a wide range of living organisms such as bacteria, fungi and animals. Various luciferins, the small molecules prone to light emission upon oxidation, have been derived by evolution from unrelated biochemical pathways. Oxidation of these molecules is catalysed by non-homologous enzymes, luciferases, to create a palette of light-emitting reactions that are different in colour,

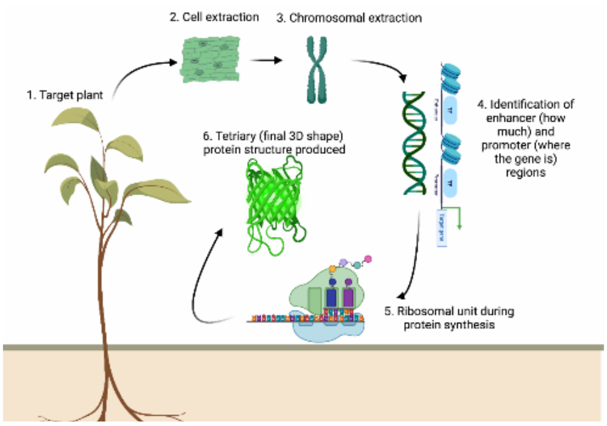

Figure 4. Illustration of genetic mutation to display the specific properties of luminance. The illustration was done using the software BioRender.

catalysis rate, cellular localisation and dependence on ATP, NADH and other metabolites" (Kaskova et al. 2016).

General principles of genetic improvement of plants are to have: a) available genetic variability in terms of the feature being improved and b) feasible genetic recombination to create offspring with new combinations characteristics, among which the desired ones are located, , which translates into the notion that specific species can be driven to mutate, acquiring the ability of bioluminescence.

4.3. *Bioluminescent Fungi*

Scotland is a country surrounded by wild nature, with competent authority bodies that protect it. An area that has mostly low temperatures and high humidity makes it ideal for the development of various species of fungi. More specific there are roughly 15,000 types of wild fungi in the UK.

But what species of mushrooms are ideal for mutation acquiring the ability of bioluminescence?

Bioluminescent mushrooms with a maximum emission of 528 nm and emission periodicity of 12 hours, are offered for the study of genetic management daily periodicity (Airth R.L., 1966). Through extensive research has highlighted which one enzyme is responsible for the luminosity effect in some types of mushrooms (American), missing from non-luminous types (European). The produced light, as in the case of bacteria, is continuous but the spectrum differs emission of the two systems, with light yellow-green colour. In Europe, luminating species is Pleurotus Olearius.

According to this research, there are three species in the UK that have this ability: a. Grey Oyster Mushroom, b. Wrinkled Peach and c. Chanterelle (Fig. 5). None of them are poisonous and only grey oyster can be found in Scotland.

Figure 5. a. Grey Oyster Mushroom, b. Wrinkled Peach, c. Chanterelle (wildfoofuk.com).

PART 2: BIOLUMINESCENT PAVILION - DESIGN DEVELOPMENT AND RESULTS [I/O SECTION

The site analysis indicated that the preferable structure design would be to a curved design following the equinox sun path. The main geometry was defined using Rhino/Grasshopper software and mesh spheres.

METHOD 1 – FORM FINDING

Twenty - four mesh spheres have been employed in this method, each of them with different radiuses. Every sphere has been subdivided in order to become smoother. The placement of every sphere is specific.

For example:

Sphere B is located -5 meters along the Z axis and 6 meters along the X axis, from the centre of sphere A (Fig.6a). Inside the sphere B, 120 points/spheres were defined, with radius of 2 meters. By removing these spheres later, the result will be to leave the imprint from 22 spheres, on spheres A and B (Fig.6b), creating recesses and pathways between them (Fig. 7).

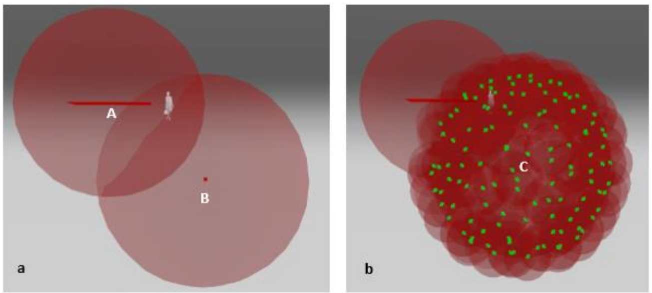

Figure 6. Computation design process – Form Finding.

Intersection

By using the Mesh Difference component, we achieved subtraction from the original sphere (A) to the populated one (B) getting the cave like geometry. Modifications were made such as the increase of spheres' radius and fluctuation, in order to produce a model that meets certain criteria such as users' height and structural support.

Variations

Modifications were made such as the increase of spheres' radius and fluctuation, in order to produce a model that meets certain conditions. For instance, either users' height or provide enough space at the back side of sphere A etc. Furthermore, the connection existence between the spheres A and B, in order to provide support to the structure.

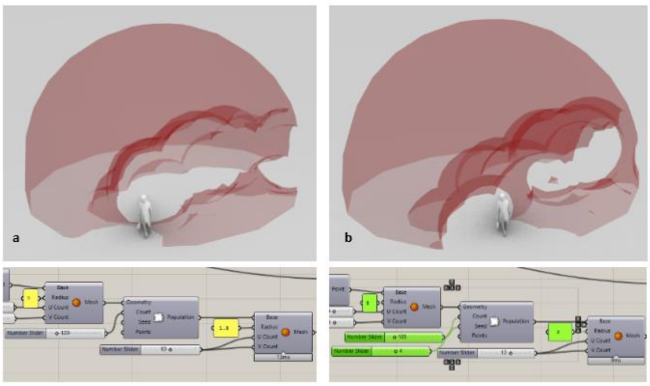

Figure 7. Computational design process – Grasshopper modifications.

By defining the geometry, three basic spaces are created that can be used. The first is an atrium space which had direct communication with the environment. Furthermore, the user will be able to spend time sitting and enjoying the good weather conditions (Fig.8b space 1). The second space was created between the 2 spheres where a pathway has been formed and the user can cross it during their walk (Fig. 8b space 2). The third space is located at the back of the spheres and is surrounded by a dome. A computational design process is described below to apply a honeycomb pattern to the dome (Fig.8b space 3).

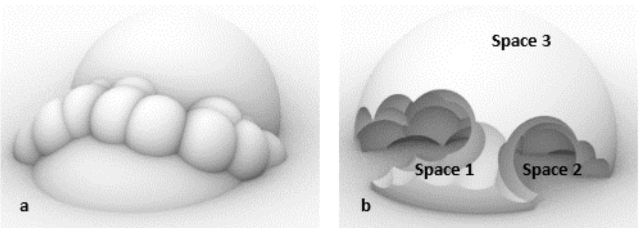

Figure 8. Final form before and after sphere subtractions.

METHOD 2 – CANOPY

After defining the accommodating surface, the honeycomb pattern was defined by grasshopper (GH), e.g. the number of hexagonal cells on U and V directions (Fig. 9a). Hexagonal cells were adapted and scaled as per design considerations. This process was implemented with the Pull Point component in GH. A curve geometry with the mapping points was defined and rescaled. The canopy's edge was selected and offset inwards (Fig. 9b), which was employed as an attractor (virtual magnet) and either attracted or repelled hexagonal cells whilst allowed for honeycomb cell resizing (Fig. 9).

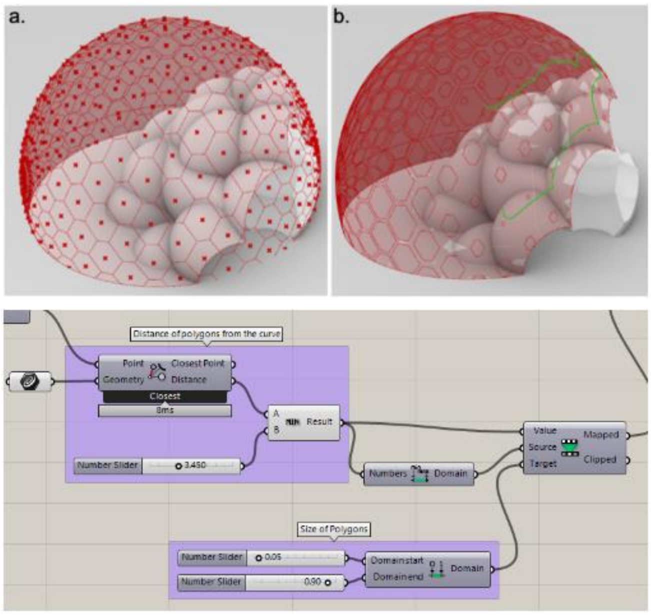

Figure 9. Computation design process – Canopy.

METHOD 3 – ROOT SYSTEM

The third computation design method evolves around the shortest walk algorithm and the generation of an organic form resembling a root system, that stems from the base of the dome and with predefined branches expanding till the dome ceiling.

The first step includes defining and counting points of interest. The larger the number of points, the higher the density of the branches that

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reach the top. After tests and modifications, the optimal number of points for the present design was 20 (Fig.10c box on the left). The main goal was to create a network of curves connecting all points. This was accomplished by Proximity 3D. The way proximity 3D operates is for every point check and its first degree neighbours, identifies the closest "X" number of neighbours generating a predefined number of branches, in this case 10 branches/points (Fig.10c box on the right). For each of these branches/points, 5 first degree neighbours are identified and connected, resulting for the present design in 50 lines in total. The number 5 results from the default number given by Proximity 3D (Fig.10c bubble). Additionally, the Shortest Walk component (Fig.10d) identifies the shortest / smoothest path from one point to another. This path is described as a line segment as depicted to Fig. 10d.

Overall, the dome geometry was predefined enabling the characterization of branch growth directionality, limit, and final end points by parametric design. The root system will not provide structural support but will provide user resting places within the structure (Fig. 10b).

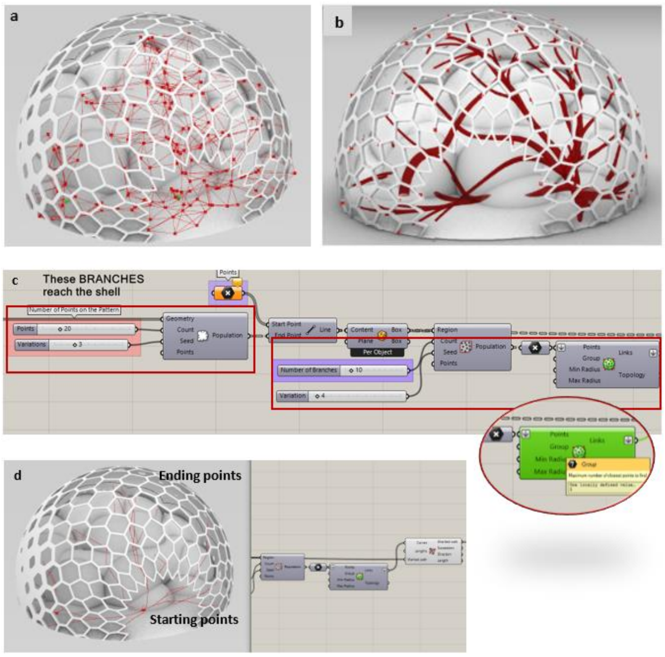


Figure 10. Computational Design Process - Root System.

BIOLUMINESCENT PAVILION DESIGN

The structure resembling twenty-four merging spheres, one of 7-meter radius, one of 8-meter radius and twenty - two of 2-meter radius made from Kerto-Q LVL plates. The pavilion's wood plated structure exhibits a thickness of 100-millimeters with a maximum height of 7.10 meter and a maximum width of 11.75 meters., which provide a shaded space for the new centre point of urban live.

The individual laminated wood plates (LVL) are generated by cutting vertically and diagonally in two directions, left to right – right to left in 0.80-centimeter distance between the wooden plates. (Fig.12b)

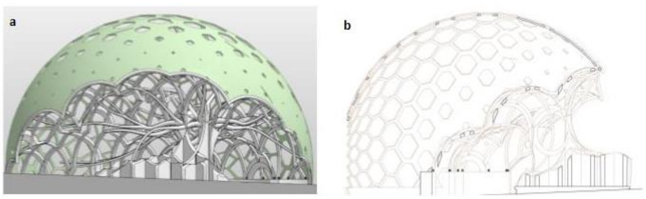


Figure 11. a. Final design of the Bioluminescent pavilion and b. Section Profile.

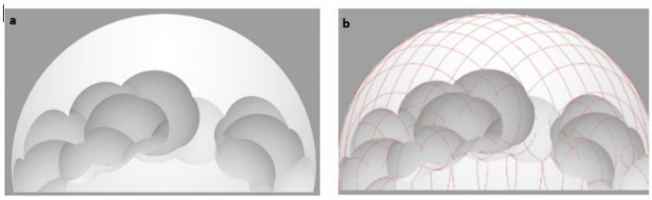


Figure 12. a. Outline of the Bioluminescent pavilion and b. Rhino-Model of the wooden structure for the Bioluminescent Pavilion.

COMPONENTS

Foundation

The foundation is shaped according to the imprint left by the spheres by cutting them transversely, during the creation of the digital model. The front part corresponds to the sphere with a radius of 8 meters, the middle part corresponds to the spheres with a radius of 2 meters and finally the rear part corresponds to the sphere with a radius of 7 meters. The lower parts of the main structure will be placed in the front part, the top parts of the main structure in the middle part and the canopy in the back part (Fig 13).

Root System

The root system will be placed at the front of the structure while working as a support for the climbing plants that will be added at the end. In winter it will give a feeling of a dry tree while in spring it will bloom, thus achieving its emergence of diversity of each season.

Main Structure

The timber plates vary between **0.50** to **5.40** meters in length, and the width of the Kerto-Q LVL plates is of 100-millimeters. The Pavilion consists of two types of timber plates, here represented as either brown or white, which constitute one hundred fifty-nine (159) pieces in total with a total surface area of about 220 square meters of laminated veneer lumber. In the lower part of the structure, brown pieces are discontinuous with white being continuous plates, whilst the opposite is true for the upper structure. In the lower component, twenty – four (24) white and brown components are included. While the upper structure is constituted by a total of one hundred thirty-five (135) components (Fig.15).

Canopy

The canopy consists of two hundred twenty-three (243) bespoke, single components of a total area of 319.7 square meters made from plywood. The canopy's thickness is 100-centimetres, with fifteen (15) different hexagon designs (Fig.16a and Fig. 16b). Hexagon design dimensions vary from 145 centimetres by 128 - centimetres (145cm x 128 cm) to 128- centimetres by 60- centimetres (128cm x 60cm). The hexagon timber panels are cut by a computer-controlled robot from large rectangular panels of a single plywood piece, and glued together, to minimize cut loss.

Prefabricated wooden assemblies, each consisting of one to three hexagonal pieces, connecting with wooden connectors - which will form the pavilion's canopy.

Considering that the largest pieces have dimensions of 145 centimeters by 128 centimeters and the average opening of the hands of a man of medium height is equal to his height (the proportions of the human body according to Vitruvius), then a man with an average height of 170 centimeters can comfortably carry a large hexagonal component. Based on the above finding, three types of compositions of prefabricated wooden assemblies were selected, each consisting of one hexagonal piece (dark grey), two hexagonal pieces (light grey), and three hexagonal pieces (white) (Fig.18).

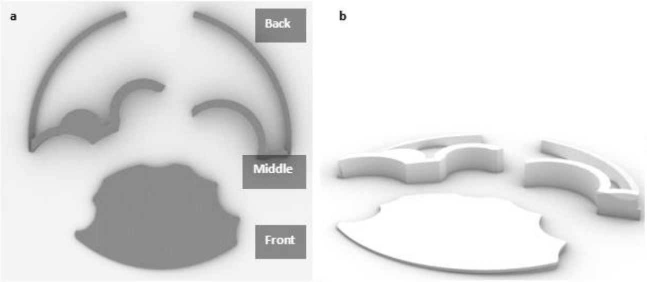


Figure 13. Parts of foundation components.

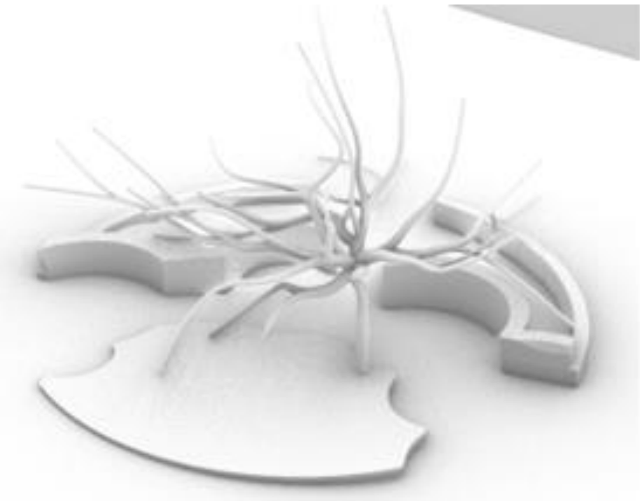


Figure 14. Bioluminescent pavilion – Root System

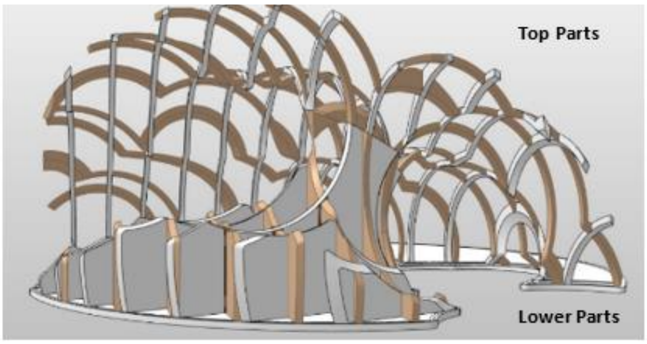


Figure 15. Main structure's components lower and top parts.

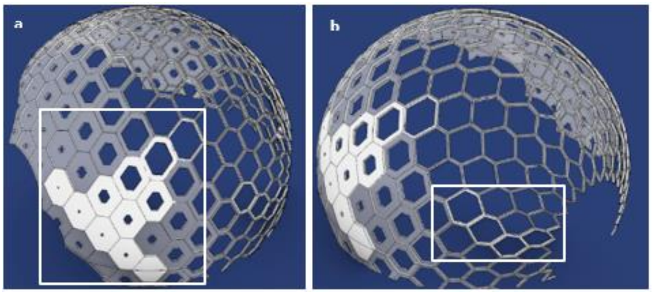


Figure 16. Illustration of fifteen different hexagonal panels.

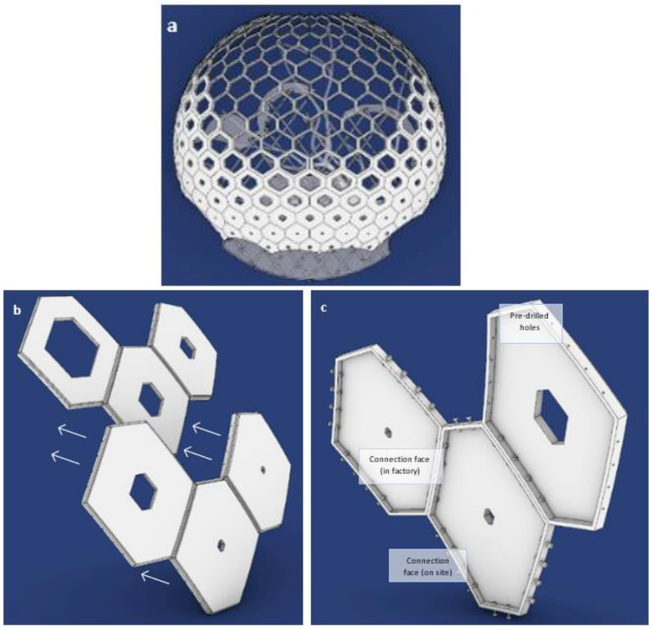


Figure 17. a. Canopy Top View, b. Illustration of canopy system, c.. Component design including wood connectors and pre-drilled holes.

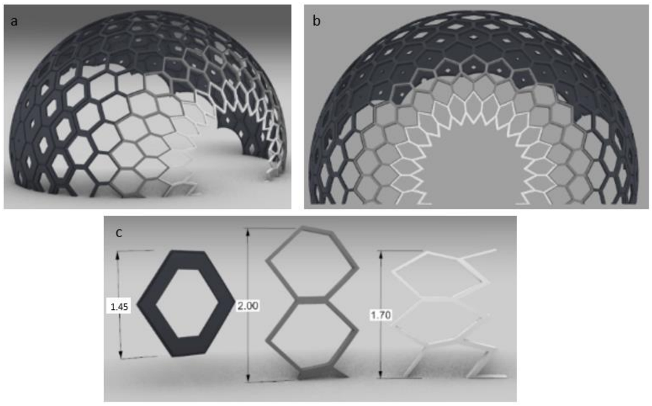


Figure 18. Types of hexagonal pieces.

CONNECTION DETAILS

The main structural components are joined by four different types of connectors. Type A: **AE.** Connects LVL elements with foundation components. Type B: **Concealed Beam Hanger**. Connects the twenty-four elements from lower part together, while the top parts are joined together by the type C: **ATFN** connector. Type D: **Wood Connectors** are used for joined the hexagonal panels.

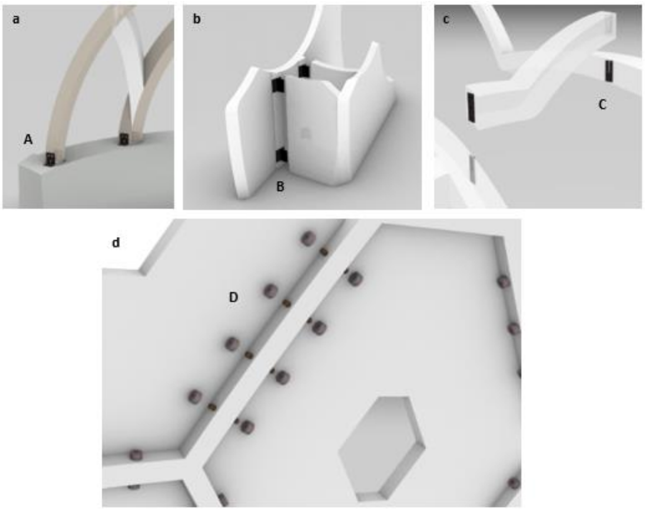


Figure 19. Building System: Illustration of the Bioluminescent Pavilion.

CONSTRUCTION PROCESS

Foundation: Work will begin with the definition of the foundations of the construction, defining not only the foundations' reinforcement, but also the root's system. Once the shapes are defined using molds, the concrete will be poured and then we will proceed with the reconstruction of the main construction.

Main Structure: First Kerto-Q LVL continuous plates will be installed. The plates are connected to the concrete slab using type A connectors, then the discontinues plates of the lower part of the structure will be connected to the continuous plates using type B connectors.

Finishing with the first phase of the composition, we will place the continuous plates of the upper part in the same way, starting with the wooden plates of the "column" in the centre. Continuous plates will be connected to the concrete slab in the middle, but also to the lower parts continuous plates of the column. The connection of the continuous plates and discontinuous plates will be done with the connectors type C.

Canopy: The assembly will start from the bottom up, connecting the hexagonal plywood plates to the concrete slab located at the rear of the structure. The connection to the plate will be made with type A connectors, the connection between the plywood components will be done with type D connectors. Extensive scaffolding will be required to complete the construction in order to place the last pieces at the top of the construction.

Vegetation. Climbing plants and Fungi: The construction is completed by placing green patches on the lower part of the main structure, consisting of grass and bioluminescent mushrooms. The upper part is an ideal construction to accommodate climbing plants of the Scottish ecosystem.

MATERIALS

Concrete, timber and steel are employed in the structure depending on the various architectural and structural demands. The foundation is made of concrete, the composition of the main structure and canopy are made of timber (laminated veneer lumber - LVL) and there are also 4 types of connectors made of steel and wood.

- Foundation - Foundation – Concrete Material Design
- Main structure – Kerto LVL Q Material Design. These panels are load bearing, incredibly strong, bracing and dimensionally steady.
- Canopy – Plywood. For timber shells, a bidimensional structural behaviour of the parts is required, thus any kind of directional product such as LVL panels had to be discarded. The choice range narrows to quasi-isotropic engineer wood products and thus the only two options were using either CLT or plywood panels. Plywood is far easier to work with, and it is available in thinner and smaller panels while it is easier to handle.
- Root System – LuminTech. innovative material will be applied, reinforced glowing concrete. As stated on its official website of LuminTechis "a patented luminescence technology that gives materials, especially concrete, technical and decorative properties".

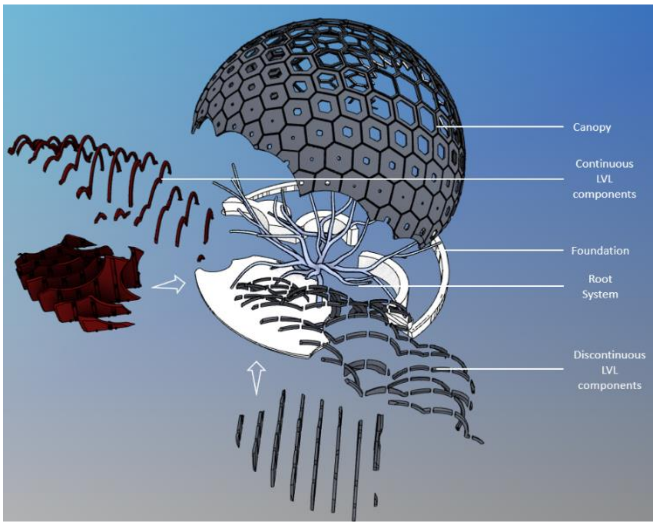
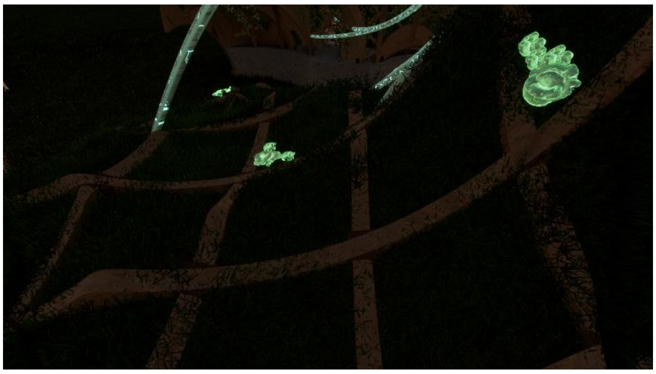


Figure 20. Exploded View.

RENDERS



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