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EUPHORBIA: MASS TIMBER STADIUM

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ABSTRACT: The key concepts of material efficiency, lifespan, design for manufacture and assembly (DFMA), design for flexibility of use and design for disassembly and reuse, are currently at the forefront of mass timber development. The role that timber must play in decarbonising the construction industry is of vital importance, replacing the more conventional building methods building established in the last century, mainly using concrete and metal; materials and ways of building that are widely blamed for excessive amounts of carbon dioxide emissions. These topics are at the centre of our architecture philosophy, both in research and practice. In this spirit, we present "Euphorbia," a mass timber stadium in Galatsi, Athens, designed by KAAF – Kitriniaris Associates Architecture Firm in collaboration with timber engineers and consultants.

KEYWORDS: Mass Timber, Energy Performance Design, Sustainability, Material Ecology, DfMA, BIM

1 INTRODUCTION

Use of mass timber has been put forward as one solution for the construction industry to address its contribution to climate change. It has the potential to transform the industry, but its potential impact on design remains to be seen. Even though mono-materiality comes to the foreground, mass timber design is still connected with standardized manufacturing processes lacking aesthetic expression as an equivalent form of architecture quality.

On this point, throughout our case study it is essential to interconnect architecture, engineering, science, art, culture, and aesthetics under the umbrella of a holistic transdisciplinary target focused on mass timber design and construction. To this end, the paper analyzes three main topics. The first is related to the mass timber performance research methodology applied to the mass timber stadium; the second, to the mass timber design and fabrication techniques; the third, to the quantitative analysis of the project. This in turn, is related to the calculation of the number of trees to be used for the construction of the project, the total CO2 stored in the building mass, and the number of projects that could be constructed per forest growth in Greece.

2 MASS TIMBER PERFORMANCE

One of the first major efforts to reduce the consumption of energy and consequent emissions in the built environment has been the introduction of energy efficiency through several incentives, policies, and norms. The large release of carbon in recent centuries can, to a great extent, be attributed to urban life. Our cities are growing. Currently urban areas consume some 67 to 76 % of all primary energy and cause 71 to 76 % of greenhouse gas emissions. [1]

Figure 1: *Exterior Perspective from the pedestrian corridor*

2.1 GOVERNMENTAL POLICIES

As awareness increases and governments and regulatory bodies around the world begin to understand the need to regulate embodied carbon, the industry is having to quickly establish consistent methods to measure and quantify the impact of the materials they use to build, and to benchmark what 'low carbon' should mean to meet environmental targets.

With improvements in thermal fabric and operational energy having historically been the target of sustainability agendas, the significance of embodied carbon has increased and is subsequently moving to the forefront of political agendas. Building with wood not only provides embodied carbon benefits through the substitution of familiar, highly carbon intensive conventional building materials such as steel and concrete, but wood also stores biogenic carbon absorbed during the life of the trees.

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2.2 CARBON SEQUESTRATION

The use of mass timber construction has the potential to counterbalance short-term declines in the carbon stock of forests [2]. As they regrow, they will renew their place in the carbon cycle, absorbing carbon dioxide. In general terms, as global temperatures rise, increasing the effects of climate change on forests, the relocation of carbon from the forest to the urban environment may counterbalance these effects, along with those caused by dwindling land-based carbon sinks.

The carbon sequestered in a tree has already been absorbed from the atmosphere. The benefit of sustainability and responsible construction is to protect wood so as not to release carbon back into the atmosphere [3]. So, the benefit is that as long as it comes from a sustainable forest, those trees are allowed to regrow. This is one of the reasons for building with wood and not leaving trees unprotected from fire and decay. But this concept has a duration of 60-70 years. The longer the lifespan of the structure, the less risk is involved. The answer to these questions is that the right balance must be found. We really need to focus on upfront carbon to see the implications that may be caused at the end of a project's life.

2.3 LIFE-CYCLE ASSESSMENT

The construction sector is responsible for over 35% of the EU's total waste generation and accounts for about 50% of all extracted resources and an estimated 5-12% of total GHG emissions. Passive design minimized energy demand as well as using energy from renewable sources. Now industries focus on how to balance the embodied carbon within the building either through offsetting – the scheme of being able to plant trees - or by sequestering carbon within the building. Material choices minimize embodied carbon and sequestered carbon as off-setting. So, we should focus on making the building fully sustainable.

Through this process an understanding of the direct relationship between the lifespan of building components and materials and their overall embodied carbon impact has been established, that means we must consider not only the immediate carbon cost, but also the maintenance requirements, how these can be minimised, and the lifespan extended. [4]

2.4 MATERIAL ECOLOGY

For timber components which store carbon, lifespan is even more significant. The longer these components and elements are utilised within a building, where they are protected from damage and decay that would re-release their stored carbon, the greater their contribution to the new 'carbon store' within the built environment, which can act as an urban forest. [5]

Nowadays, traceability of the materials and the embodied energy are critical aspects of the design process to inform the value chains and distribute the material catalogues throughout each project life cycle from certified forests with responsible management of manufacturing, assembly, and reuse. Mass timber components should last longer than 60 years, which is the equivalent of the time needed for a tree to grow, mature and be logged for construction purposes. The lifespan of the timber components is 30-300 years, of the envelope 60 years, of the interior 15 years, and of systems 10 years. In our case study, it is important to examine the following:

Materials
- Choice of materials and their attributes
- The distance between the site of manufacture and the construction site
- Ergonomic application

Their lifespan and plans for recycling them

Construction
- Airtightness of the building shell
- Controlled ventilation with heat reclamation
- Internal air quality

The total energy footprint in relation to the environment
Collection and reuse of rainwater
Use of solar and wind power

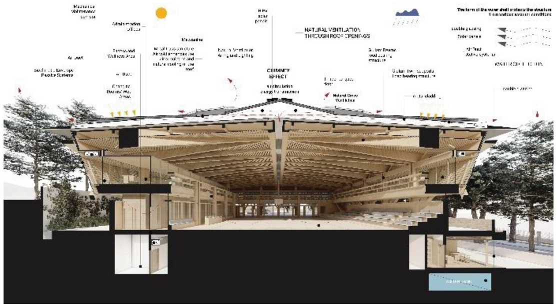

Figure 2: Perspective Section of the Mass Timber Stadium

3 MASS TIMBER DESIGN

Design for disassembly (DfD), is related to the component's lifespan so if components last long enough, they are more likely to achieve net-zero KgCO2e/m2. To this end, and given that there are different levels of demountability, it is necessary to translate our concept in relation to the full disassembly or reassembly potential of the structure in a different location, or the partial reuse of parts of the project's components such as glazing, timber panels, CLT decks, GluLam components, and metal connectors. Components must be easily identifiable with quantitative and qualitative data available for future uses (eg. through digital twins) and clear documentation of the method of deconstruction is important. The BIM model gives digital insight of the building to all its stages. In our case, building as a material catalog in this huge dataset is critical to understand which material is used and to review the quality of each component.

After stone, wood is the most ancient reusable construction material of natural origins, yet the shared global concerns of our time are leading to renewed architectural norms. Since the dawn of industrialisation through to today, even though architecture is constantly becoming more complex, the building industry does not seem to make effective use of contemporary computational fabrication technologies. New questions regarding the manufacturing processes have been addressed, while at the same time a new way of architectural tectonic has emerged by shifting the paradigm from digital design manufacturing to evolutionary robotic manufacturing of natural forms.

3.1 CONCEPT

The main architectural concept of the project is related to a plant called Galatsida, a *Euphorbia* genus. It is believed that Galatsi area in Attica was named for the Galatsida plant which is abundant in the area. The name comes from the milky juice secreted by the shoots and leaves of *euphorbia*. *Euphorbia* is a large genus of plants in the *Euphorbiaceae* family, represented in Greece by more than 40 species. A special feature of euphorbias is their cup-shaped inflorescence, which is why it is called "kyanthos" from the ancient Greek word for cup. The mass timber stadium is located inside the premises of the "Veikos Grove" in Galatsi and has a total gross buildable area of 3.000 sqm.

The purpose of the design, according to the Municipality initiative, is to create an iconic, sustainable, passive-design stadium made of ecological and biobased materials such as wood, which will promote the principles of recyclability, reusability, energy performance, traceability, and material ecology through athletic values, by accommodating local basketball games, training and gymnastics facilities, and administration offices.

On the ground floor is the sports area and the central entrance for spectators and athletes. Spectator stands are in the northwest wing, numbering 200 seats, and there are separate restrooms for spectators. The stands communicate with the upper level through two linear staircases, allowing more standing spectators. The southeast wing hosts the reception, the athlete and referee changing rooms, and the two central stairways that connect the ground floor with the basement and the upper floor. Also on the upper floor are the administrative offices which overlook the playing field, while the remaining wings on this level can host additional sporting activities. The basement includes additional changing areas, the central space of the gymnasium, storerooms and engineering facilities. In the northwest wing the basement becomes the ground floor as it is at pedestrian street level. This area is reserved for the sports associations. The case study has controlled air flow, is watertight, the internal air quality is excellent, while part of the necessary energy production uses BIPV.

Special attention is given to the correct application of the connection between elements of different materials to avoid thermal bridges, through automated control of air conditioning and temperature in the building interior according to maximum and minimum public use of the space.

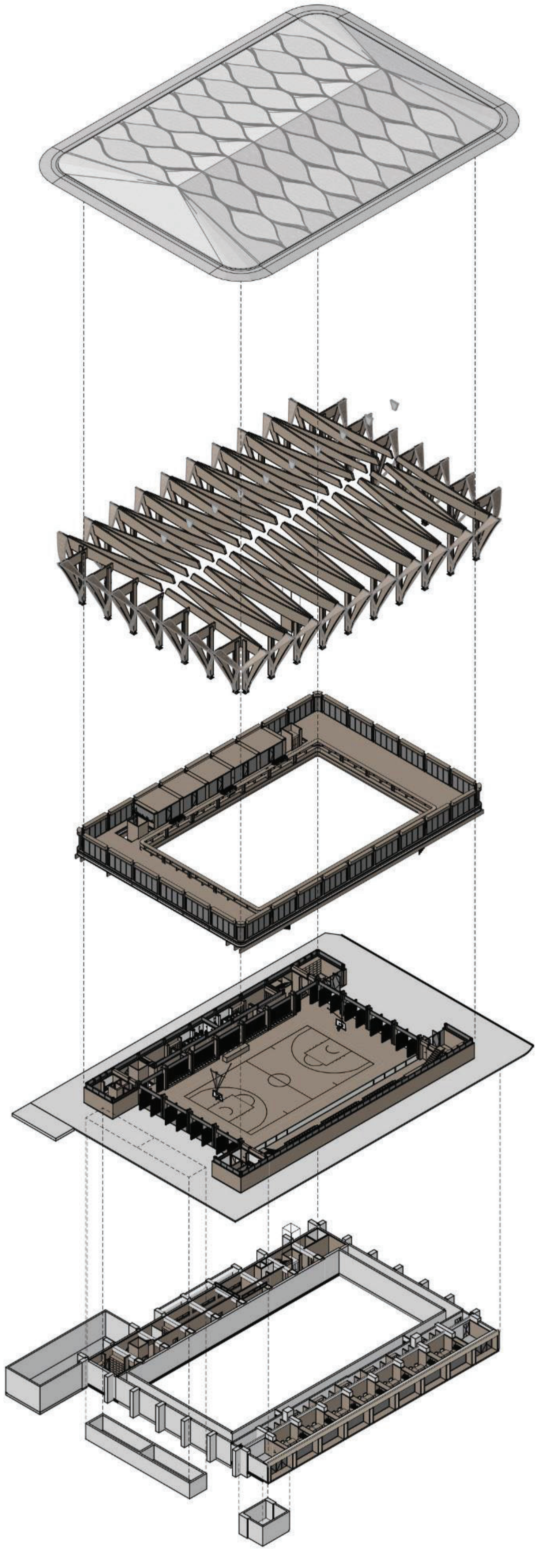

Figure 3: *Axonometric Exploded Analysis Diagram*

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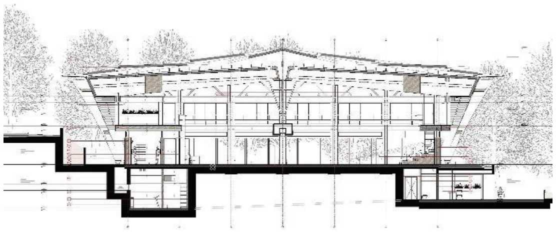

Figure 4: *Cross Section of the Mass Timber Stadium*

Rainwater is collected in a special tank from the tiled surfaces of the surrounding area and the roof. Using special filters and recirculation, it is reused in the changing rooms and restrooms. Part of it is reused for irrigating the surrounding Grove, while there is a second tank for fire safety.

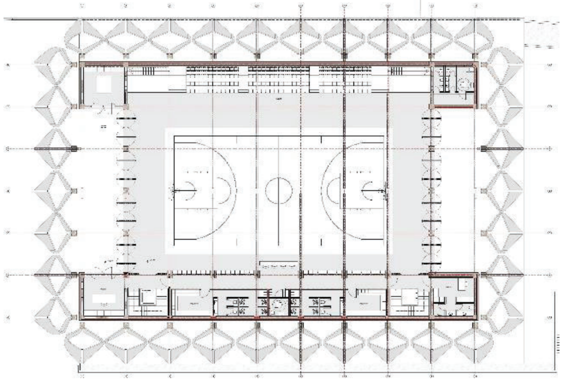

Figure 5: *Main Plan of the Mass Timber Stadium*

3.2 TIMBER LOAD BEARING STRUCTURE

The mass timber stadium is designed so that the Load Bearing Structure consists of:

- Wooden elements for the sections above the final gymnasium level, and specifically, glued timber (GluLam, GL32 category), non-glued timber (plywood) and cross-laminated timber (CLT). Supplementary metal elements are used when judged necessary, mostly as connecting elements but also for rigidity. These elements relate to the ground floor, the upper level, and the roof.
- Reinforced concrete for the sections beneath the ground, and more specifically beneath the final gymnasium level, partially extending into view at the pedestrian street level under the gymnasium. The foundations of the building and all the underground sections are constructed of reinforced concrete. These elements are in the first and second basements.

The load bearing system of the gymnasium is organised on a 5 metre rectangular grid, with seven repetitions on the one axis, and ten on the other, with general dimensions of 45 m in length and 30 m in width.

The foundation is strengthened around the perimeter of the building, since the load bearing elements are arranged around it, while internally a grid is formed from strap beams parallel to the smaller dimension of the building. These beams receive the horizontal loads exerted on the columns supports, while transverse beams are used mostly for the lateral stiffening of the first strap beams. On these beams lies the ground floor slab made of reinforced concrete.

3.2.1 BUILDING SHELL

The **shell** of the structure consists of 10 identical isostatic frames, bridging a 30-metre span. They are symmetrical and consist of beams and columns as shown in the drawings, functioning as a three-pin arch, since they include three joints within their plane: one joint at the support of each column and one at the top, where the two beams are connected. Each three-pin frame consists of the following:

1. **Two twin vertical columns,** 20 by 60 cm cross-section, 8.40 metres high.
2. **Two main beams** between the twin columns, slightly inclined. The main beams are approximately 18 metres long, 20 cm wide, and variable in height from 1.65 metres at the point of connection with the twin column, to 1.05 metres at their other end.
3. **Two deviating beams,** of the same dimensions as the main beams above, only deviating horizontally comparing to them, symmetrically arranged on either side of the twins columns. These beams connect to one another at the middle axis of the gymnasium, at half the distance across the 5-metre grid, at 2.5 metres.
4. **An inclined column** between the two twin ones, sloping outwards. Its external side is curved, resulting a variable cross-section. The base of this column starts from a cross section of 20 by 60 cm and ends at the top, under the roof, at 20 centimeters by 96 cm. A UPN 140 stainless steel element is added alongside this inclined column so as to stand in for the static function and allow easy replacement of the timber member.
5. **Two curvilinear V-shaped members** emanating from either side of the inclined column and extending to the top of it, at face level, with the flare of the geometry occurring approximately at mid-height. The inner stems of two arrays in a row connect in the middle, at half the distance of the 5 meter grid, at 2.5 meters.

   The 3 aforementioned elements (1, 4 and 5) have a common starting point in a metal joint at the base of the building on the ground floor.
6. **Horizontal beams** between the twin columns, extending towards the interior of the gymnasium, on which the CLT plates of the mezzanine rest. Their cross-sections are 20 by 80 centimetres with a length of 7 metres for the

three sides of the gymnasium, except for the beams that support the loft above the spectator stands, which have a cross-section of 20 by 35 centimetres and a length of 3.5 meters.

The use of a large number of beams: 1 main beam and 2 inclined beams, each 5 meters long and with a large cross-section, allows their flexural-torsional buckling to remain non-critical and thus they do not require flexural-torsional security against wind, snow, and earthquake loads. However, it is necessary to ensure against flexural buckling, and for this reason a dense mesh of blinds is placed around the middle of the static height of the beams which also has an architectural function related to the acoustics and lighting of the sports area.

The shell is completed on the upper surfaces with composite frames of wood and plywood with thermal insulation within, which are built into the ground and bolted to the upper seat of the main and diagonal beams.

The small facades of the building are shaped in a similar way to the large ones, with vertical and inclined columns and diagonal elements. More specifically, on the two narrow sides of 30 metres, the load-bearing body consists of 7 groups, each arranged on the 5 metre framework. Each of these groups consists of the elements described previously. More specifically: a twin vertical post (1), an inclined post (4), two curved V-shaped members (5) and horizontal beams with cross-sections of 20 by 80 cm and 7 metres long (6). Instead of the main beam (2) at full length, there are shorter beams that extend until they touch the outer main beams of the long sides, 20 cm wide, about 1.5 metres high and 3.85 metres long.

Figure 6: *Main Structural System of the Mass Timber Stadium*

The out-of-plane stiffness of the beams is achieved by the frames formed by the vertical posts and a grid at their upper level. This network is formed at the upper end of the twin vertical posts (member 1), there is a system of double, parallel GluLam wooden beams, and two more inclined ones, which runs throughout the gymnasium and provides rigidity at the face level.

3.2.2 BUILDING CORE

All areas of the internal are made of CLT and GluLam. All floors are made of CLT, and so are the walls, whereas vertical members of GluLam in conjuction with steel members are used as columns between openings. Higher than the ground floor spectator stand, a 35-meter-long and 3-meter-wide loft is formed. Its floor is again made of CLT, like all other areas, only this floor is partly suspended by the main beams of the roof, and partly supported by the aforementioned 20 by 35 cm GluLam beams.

On the outer side of the corridor in the changing room area there are twin columns 20 by 60 centimetres cross-section and 4.8 metres high, between which the horizontal beams (member 6) of the changing room side terminate. On them lie the CLT plates and office spaces of the upper level. A corresponding function is served by the twin columns on the two narrow sides, with the CLT plate resting on the horizontal beam system on each of these sides. The stairwells on the changing room side, as well as the lift core, are made of CLT slabs and walls respectively.

Figure 7: *Interior Perspective of the Basketball Court*

3.2.3 ROOF

The roof is made of a metal frame and fiberglass panels on curved surfaces which, with an appropriate slope, channel the rainwater into special channels which end in the perimeter gutters. The choice of fiberglass material has a double meaning. On the one hand, it is a material with great resistance to weather conditions, and on the other, it helps to reduce the burden of additional loads on the construction. The metal frame is placed on the underlying wooden cross-beam and plywood cladding, the outer surface of which is protected externally by a vapor barrier and water resistant membrane. The construction consists of numbered pieces which will be fabricated off-site with CNC machines, and will be transported and assembled on-site.

4 FOREST GROWTH

Forests cover 31 percent of the planet. Approximately half of this forest area is reasonably intact, and more than one third is primary forest. The net loss of forest area has decreased significantly since 1990, but deforestation and forest degradation continue at alarming rates resulting in significant loss of biodiversity. The world is not on track to meet the target of the United Nations Strategic Plan for Forests to increase forest area by 3 percent worldwide by 2030 [6]. Urban and built-up areas are equal to 1% of the total land area of the world. As forests are vulnerable to wildfires and decay it is important to secure forests from

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releasing carbon back into the atmosphere. Apart from world forest management plans that have already been implemented and increased in the last decade, the other way to secure carbon from being released is to store it in buildings.

4.1 WORLD FOREST AREA

The world forest area is equal to 4 billion hectares. In the last 30 years, world forest losses demonstrate an absolute change of -177 million hectares, or a relative change of -4 percent. The number of trees in the world are equal to 3 trillion trees with an average of 22,500 trees per square kilometer and 422 trees per capita. The report shows that the over the last 30 years, -35 million hectares of primary forest were lost, a relative change of -3 percent. A planted forest gained +105 million hectares, a relative change of +56 percent, while the naturally regenerated forests have lost approximately -200 million hectares, a relative change of -8 percent. [7]

4.2 EUROPEAN FOREST COVER

By considering the increase of forest growth in Europe in the last 30 years, between 1990 (208 million hectares) to 2020 (227 million hectares), we notice that there is an annual change of +0.3 percent, with a forest growth of 19 million hectares, equal to 650 thousand hectares of forest growth per year, while the forest area in Europe per capita equates to 0.33 people. [8]

4.3 FOREST COVER IN GREECE

Forest area in Greece was reported at 30.27 percent in 2020, according to the UN F.AO & the World Bank collection of development indicators, compiled from officially recognized sources. In 2020, forest area for Greece was 39,018 sq. km (3.9 million hectares). Forest area of Greece increased from 36,304 sq. km (3.6 million hectares) in 2001 to 39,018 sq. km in 2020 growing at an average annual rate of +0.38 percent. [9]

4.4 QUANTITATIVE ANALYSIS

With the aim of linking mass timber construction to the forest growth in Greece, we calculate that 1,825 mature trees (by taking into account a mature tree with a height of 30m and a trunk diameter of 0.75m) required for the construction of the mass timber stadium, 2,500 tn of CO2 on building mass (by taking into account that 1 tree absorbs 1tn CO2 and releases 727 kg O2 per cubic meter of growth), while 1.7 projects per hour or 40.7 projects per day or 14,872 projects per year could be constructed per forest growth in Greece. The total wood product calculated for the mass timber stadium equals to 2,500 m3 including off-cuts.

5 CONCLUSIONS

Through the analysis of the case study, the following points have been evaluated:
- understand mass timber structural solutions for larger scale, big span spaces, as well as how these systems deal with the performance aspects and the occupant benefits of exposed timber surfaces within these buildings.
- consider building longevity as well as flexibility for future change of use and adaptation at the design stage.
- focus on key aspects which influence the ability to disassemble a building into components that can be re-used at end of life, as opposed to demolition.
- highlight how the significance of building and component lifespan on the embodied carbon of buildings is critical for consideration of sequestered carbon within LCA analysis of biobased products such as wood.
- calculate the number of trees per project as well as the number of projects per forest growth per year as a quantitative analysis of a mass timber building.

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