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Benefits of Glulam Timber Roof Structure for Airport Passenger Terminal Buildings

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Abstract

Airport passenger terminals vary in shape, form and interior design. Most of the terminals' roof structure at the uppermost building level is a steel structure with a curved shape and false ceiling/cladding to give a pleasant view. Very few buildings have a concrete roof at this level. Nowadays, designers look for green building materials such as timber instead of steel, as wood has many advantages. Architects understand the importance of architectural features of the passenger terminals while conceptualizing the design to create an attraction with an element of uniqueness. An airport in the Philippines utilized Glulam as a roof structure material for the passenger terminal building and achieved its design intent matching local culture. The terminal received appreciation from all the stakeholders and proved the rationale for choosing this material. It is also essential to be aware of the limitations of Glulam material, and adequate care is taken during planning, implementation and maintenance of the asset. Selection of suitable materials, construction methodology and project management ensures delivery of the projects in time.

Keywords; Passenger Terminal, Glulam, Fire Resistance, Climate change impact, Moisture content

1. Introduction

All the airport passenger terminals cater for the same processes, but no two airport terminals look similar; they are unique in the architectural design, finishes, shape, size and service delivery. Some airports try to showcase the local culture in the design elements. It is established that the environment and look inside the terminals profoundly affect the sales volume of the commercial establishments inside the terminal. Satisfied passengers' word of mouth has a significant effect by attracting more passengers to pass through the airport. Aviation activities contribute to environmental impact. The airport developers thus design and construct the airports with green & sustainability concepts in mind to minimize the impact and make them attractive with beautiful and unique architectural design. More common practices are using energy-efficient lamps, pumps, air conditioning equipment, LEED certification, rainwater harvesting, etc. This paper describes the use of wood as a roof structure instead of steel, with an example of an airport terminal constructed with such material. Section 2 describes the summary of the literature review. Section 3 describes the use of Glulam material for the roof of the passenger terminal at Mactan Cebu International Airport (Philippines). Section 4 summarizes the main findings, the concluding part of the paper.

2. Literature Review

2.1 *Architectural design considerations for the airport passenger terminal*.

To learn about passengers' preferences in airport terminal building design in the Check-in and Gate hold areas, a survey was conducted at Schiphol airport in Y 2018 with 346 passengers. The survey result showed that their preferences were i) curved shape floor layout and roof ii) green plants within the building iii) long spans iv) interior with materials in while colour iv) pleasant lighting [1].

Commercial revenues at an airport are vital for the airport operator. Reference [2] identifies strong correlations among product's quality, product range, store aesthetics, service to customer and customer inclination to patronise the retail store. Reference [3] finds that atmospheric variables influence a wide variety of consumer evaluations and behaviours.

Terminal buildings of medium size and above are generally a minimum of three levels with departure at the top level, arrival corridors/services at the intermediate level, and arrival hall at the ground level. Commercial areas are concentrated at the departure area and arrival areas of international terminals. Most recently developed terminal buildings characterize their long-span structural

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systems. A long span achieves a clear space without obstructions to accommodate the constant change in passenger flow. An unobstructed view with a long span visually creates a 'high volume' factor. This concept also helps to accommodate passenger processing systems and baggage handling systems from one floor to another.

Airports and especially the terminals, are the first contact point for passengers arriving at the airport. After security check/immigration, passengers spend more time at the gate lounges before boarding the aircraft. In addition to the functional performance of the airport in terms of service delivery, the aesthetics and attractive architectural environment bring high passenger satisfaction. From the aircraft, passengers can view the terminal, its roof and façade elevation.

Modern architectural design, complex structural systems and new construction materials combine to create an architectural shape that respects local and customary privacy to match the region's famous architecture. Furthermore, such an architectural shape and structure expresses the local architecture's uniqueness [4].

2.2 *Properties of Glulam material.*

There is plenty of literature on the properties of wood as a construction material, more specifically Glulam. These studies show that the properties of such materials have been extensively analysed and that its usage has been accepted. The majority of structural materials require a significant amount of energy during production and thus, contribute substantially to the release of carbon dioxide and greenhouse gases into the environment [5]. Wood, on the other hand, grows on trees. Therefore, the forest serves as a wood producing facility. Water, nutrients, and carbon dioxide are taken in by each tree, which then uses solar energy to make oxygen and wood. If replanting is planned and implemented or managed regeneration following harvesting or felling, timber is the one material that is entirely a renewable resource. Each tree is unique in that they tend to be a variable material, results in its structural behaviour being relatively complex [6].

Climate change mitigation is another advantage of adopting value-added wood products. Wood may be utilised as an environmentally friendly building material because it is a carbon sink [7].

A study examined the possibility of lowering greenhouse gas (GHG) emissions from the construction industry by replacing multi-story Reinforced Concrete (RC) structures with timber ones. Using Life Cycle Assessment (LCA), this study compared the climate change impact (CC) of an RC benchmark structure to an alternative timber structure for four buildings ranging from three to twenty-one stories. Timber structures buildings can reduce GHG emissions, as evidenced by a negative CC in a consequential LCA. When compared with the RC constructions, this equates to a savings of more than 100% [8].

One of the most critical characteristics of Glulam is fire resistance. When wood catches fire, it usually produces char, which insulates it, thus extinguishes the fire slowly and preserves the wood's core and the structural material's characteristics, which is a considerable benefit over other construction materials [9]. Because of its wider diameter, glulam outperforms exposed steel, allowing for a slower reaction to the fire and just charring the surface at first. As a result, Glulam constructions can bear loads for longer periods and at higher temperatures, whereas steel softens and loses structural integrity around 260 degrees Celsius. Adhesives and clear surface coatings on Glulam products can increase fire resistance if needed [7].

Buildings with wooden constructions have been shown to be more robust in earthquakes due to their cellular structure, which allows it to flex. An example is the earthquake of 2011 in Christchurch, New Zealand [7].

Certain structural forms make the timber very efficient. Because loads are transferred primarily in compression and shear in the plane of the shell, shell structures are more suitable for roofs with longer spans. Roof domes of larger than 150 metres diameter and 45 metres high have been built with timber forming shell structures [7]. The most prevalent reason Glulam is employed in buildings is that it can have large dimensions and distinctive curves, enhancing the architectural design [7]. The company's manufacturing capability or the mode of transportation limits the Glulam size [10].

Glulam structures are manufactured at the factory resulting in efficient processes during production, the least disruption at the construction site and expedite the construction progress. The structures are transported in sections for ease of transportation to the site of installation. Once received at the site, they can be assembled, hoisted, and placed with minimal storage time. Thus, lesser fabrication/storage space is required at the site compared with steel structures. Also, factory-made structure means accurate dimensions with precision machines with minimal fabrication/welding at the site and thus, saving much time in the completion of the building [5].

The modulus of elasticity and modulus of rupture tests can be used to evaluate the effectiveness and limitations of Glulam beam construction [11].

This type of roof structure does not require cladding or false ceilings due to the excellent aesthetics of the roof when viewed from inside the building. The lighter weight of wood also benefits from reduced foundation sizes and other structural elements. In addition, Glulam material has better sound and heat insulation properties.

With this natural and sustainable building material, the reaction of wood to moisture is expected. Moisture content increase in the wood affects the material's strength and stiffness and results in shrinking and swelling. The presence of excessive moisture content might cause material deterioration or the formation of fungi. As a result, it is critical to accurately predict the moisture content based on observed values and measures during planning, implementation, and maintenance. In-situ moisture content monitoring of structural timber parts has recently attracted much attention. Reference [12] describes the methods to determine moisture content in wood.

Moisture content check must be included in the structural health monitoring system to study and predict structure behaviour as a monitoring program for timber structures [13]. Failure analysis based on a study of 127 timber structures shows that lack of strength as the prime reason for the failure (41.5%), followed by installation flaws (14.1%), on-site modifications (12.5 %), and inadequate or absence of design concerning environmental activities (11.4 %). Only around 11% of failures are due to the quality of wood and production processes or production concepts [14].

3. Construction of passenger terminal building at Mactan Cebu International Airport (MCIA).

MCIA is the 2nd busiest airport in the Philippines. Cebu is a popular international tourist place, and it is a gateway to tourist resorts. The operation, Management and Development of MCIA, i.e. passenger terminal building, apron and city side, was awarded on a 25 years' concession to a consortium of GMR Infrastructure Ltd (India) and Megawide Construction Company (Philippines) under Public-Private-Partnership (PPP) framework through a global competitive bidding process. The Concession Agreement (CA) was signed in the year 2014. Immediate development works included the construction of a new terminal T2 for International operations. As terminal T1 was an integrated building for domestic and international operations with segregation where required, and this terminal was handling beyond the design capacity, terminal T2 was mandated to be completed and commissioned in 3 years from Y 2015 as per CA.

Key aspects of the construction of the T2

- ✓ To cause minimum impact on existing airport operations
- ✓ Limited Land availability within the project boundary for storage of construction materials and equipment.
- ✓ Relocation of existing facilities in T2 site in order to commence the construction
- ✓ To get LEED certification for the T2.
- ✓ High seismic zone and frequent cyclone- prone with high wind speed.
- ✓ Highly corrosive atmosphere being an island.
- ✓ 65,000 sqmt floor area in three levels.

The design principle for T2 was to create a new experience for passengers accompanied by simplicity and warmth to differentiate it from coldness typified by many airports, high pitch roofs and low eaves to fend off solar heat and glare. A lightweight roof at the same time to withstand high wind speeds, charming structural form, natural material, green and sustainable.

Fig 1 shows how the architect in the case of T2 at MCIA developed the concept to reality.

The roof supporting structure were designed to withstand storms with wind speeds of 200 km/h, which are common in this region. For seismic withstand capability, as the region is in the high seismic zone, the building joints, as well as the anchoring of the main girders to the concrete structure, had to be done in such a way that they would resist the building's motions in the event of an earthquake [15], as shown in Fig. 2

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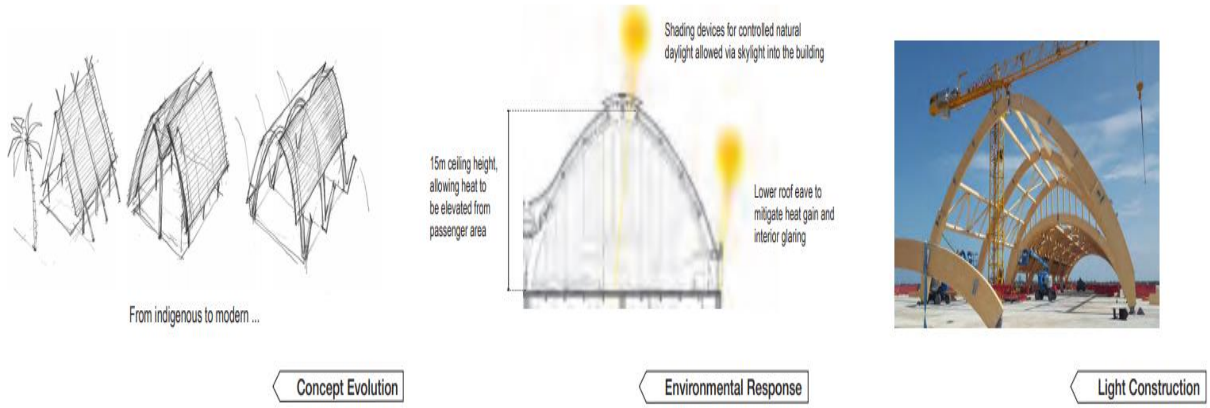

Fig..1 Development of roof design from concept to construction

Fig. 2 Anchoring arrangement.

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Fig. 3 Check-in hall with 15 m roof height and a span of 30 m (Inside view)

The architect felt the need to express the desire to provide something unique to passengers and greet and say goodbye to tourists in a unique, resort-style location. Philippine culture is rich with friendship, open and warm, and the light architecture and building materials chosen were expected to symbolise such culture. The decision was made in favour of the most sustainable of all building materials, timber, for artist's impression, eco-friendly, and established grounds. For generations, the Philippine culture has been strongly rooted in the processing of wood [15].

With a 15 metres height and 30 m span, the undulating barrel-shaped supporting roof structure required 4,500 m3 of Glulam material. The main beam, measuring 800 x 1,270 mm, and the timber beam in two halves, each 23 m long, were prefabricated at the Austrian manufacturing facility. The structural elements were shipped in three consignments to the Philippines via the "Rhine-Main-Danube Canal and Antwerp". The elements were assembled and hoisted in about three months. Thus, this airport is the first in Asia to have an all wooden roof construction. The roof was architecturally spectacular when viewed from inside and outside Fig. 3 and Fig. 4

Natural materials were employed throughout the terminal area, including "Moss" from Italy and other types of timber on the walls of washroom facilities, in addition to the green roof structure. To represent the sand of Cebu's beaches with bright sunshine, polished stone flooring with "mother–of–pearl inlays" was employed [15].

Honourable President of Philippines inaugurated the terminal T2 on 7th June 2018 and was put into operations in July 2018 as per the schedule. In his inaugural speech, the President said, "As one of the finest airports in Asia, this facility will showcase the best of what the Philippines has to offer. The masterpieces will not just add to this structure's aesthetic value, but will also showcase to the world our distinct sense of warmth and hospitality, as well as our unique and rich cultural heritage".

The airport was recognised as one of Southeast Asia's most modern airports with the commissioning of terminal T2 and won many awards.

Fig. 4 View of the terminal from the airside

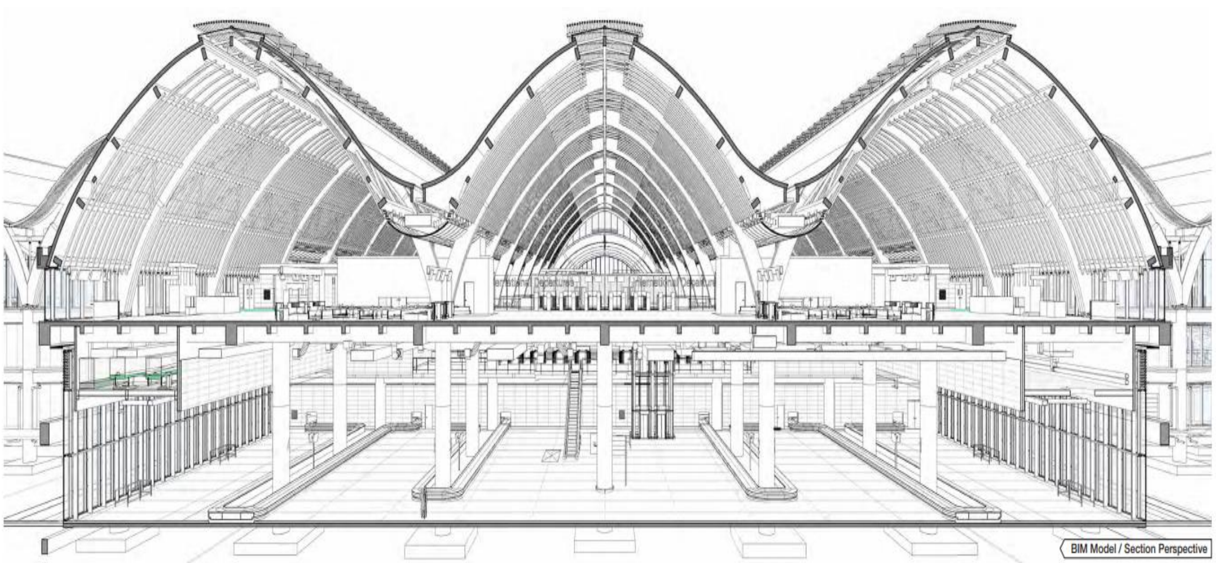

Fig. 5 Sectional Elevation with Check-in hall at upper level and arrival hall at ground level

4. Conclusion

Terminal building T2 roof with Glulam material proved effective in achieving the desired architectural views and appreciation from the passengers and stakeholders at MCIA. The selection of this material enabled to commission the terminal building in time. The cost of the roof with Glulam was economical, compared with steel as material, based on life cycle cost analysis, not on initial capital cost only. Of course, the time saved in the project has very high-cost savings and fulfilment of commitment as per CA. The joint details adopted in timber structure play an essential role in their success. The final member size depends on the joint, and design effort could be as high as 70%. Transportation costs from the production factory to the construction site and practical limitations on length while transporting, will be considered for the joint position. Hence, sometimes the joint may not be at the optimal structural locations, which is required to be considered in the design [16]. In addition, research has shown that adding stiffening components like glass fibre has improved the Glulam structures for more rigidity.

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