Exploring the Feasibility of Mass Timber Use in East Africa: The Effect of Nairobi's Climate on Mass Engineered Timber Structures

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Abstract

The construction industry is responsible for approximately 37% of greenhouse gas emissions, with materials production contributing 9% of this. To reduce these emissions significantly, the industry must look into alternative materials that are sustainable. One of them is Mass Engineered Timber (MET), known for its carbon-storage characteristic and can be used to decarbonize the building sector. MET involves glued or nailed graded timber panels to enhance structural integrity, offering economic, social, and environmental benefits. While the material has been used successfully in temperate regions, its use and information in tropical urban south cities is limited. This study investigates the climate of Nairobi and analyses any potential impact on the performance of MET and overall, assesses the city's suitability to support MET structures. The objectives of the study included analyzing Nairobi's climatic conditions: rainfall, temperature, humidity and solar radiation, assessing the potential impact of these conditions on MET and determining the necessary required protective measures. Using a mixed-method approach, secondary data collection methods and causal-comparative analysis methods, the study found that Nairobi's high average ultraviolet radiation of 13.75 UVI poses a risk to the compressive strength of MET structures made from timber with a high lignin content. To prevent damage, treatment options are applied before lamination for maximum impact. However, further research on the protective measures for the material use in the climate should be done.

Keywords: Mass Engineered Timber, Nairobi Climate, Decarbonization, Construction Materials

1. Introduction

The construction industry contributes approximately 37% of GHG emissions and consumes 40% of global energy (Sizirici *et al*., 2021). Of this, construction materials account for 9% of carbon dioxide emissions due to energy (UNEP, 2022) with steel and concrete emitting 2.3 and 2.6 billion tonnes annually. To reduce these emissions significantly, the sector must embrace alternative materials at large volumes. Mass Engineered Timber (MET) is considered an alternative material to steel and concrete due to its environmentally-friendly nature. If reinforced concrete is substituted with mass timber alternatives, almost 43% of GHG emissions are prevented from entering the atmosphere (Hemmati *et al*., 2024). Additionally, if 20% of Africa's housing is done in MET by 2050, 100+ million tonnes of CO2 emissions are prevented annually (Gatsby Africa, 2023). Makeka and Sharma (2022) indicate that Africa currently has a deficit of 56 million housing units, with low-income affordable housing comprising 80% of the figure. Building a significant fraction of this housing in MET will greatly contribute to both a decarbonized construction industry and an increased supply of (affordable) housing. Mass Exploring the Feasibility of Mass Timber Use in East Africa: The Effect of Nairobi's Climate on Mass Engineered Timber Structures Engineered Timber (MET) refers to timber or wood that has undergone manufacturing by gluing or nailing graded, sawn timber panels of a certain size together to create timber components whose structural integrity has been improved (Shang, *et al*., 2023). Various Life Cycle Assessments (LCA) done in different locations has revealed the numerous economic, social and environmental benefits of MET.

However, timber is prone to damage by various environmental factors including water and organisms. Many studies have been done on the use of this material in temperate regions, but there is scarce research covering the use of MET in other climates, for example, tropical regions like Nairobi. There is limited information about both the timber and components that go into the manufacturing of mass timber for use in certain climates. The longevity and long-term suitability of its use in the tropical climate is still unknown. Therefore, the uptake of its use in emerging markets has been minimal.

The aim of this study is to investigate the climate of Nairobi to explore its suitability to support mass timber structures. The study's objectives are:

i. To conduct an analysis of the rainfall, temperature, humidity, and solar radiation of Nairobi over the past 10-20 years.
ii. To investigate the impact of Nairobi's climatic conditions on the durability of mass timber structures.
iii. To analyse the performance of the material under Nairobi's climatic conditions

The study has used a mixed-use method to conduct the research using causal-comparative design to derive any relationship between the climate of Nairobi and the performance of mass timber structures. Additionally, the study used a non-probability sampling method to select its sample of tree species used in mass timber construction. Due to time and costs constraints, the study used only secondary methods, mostly observation, to collect data and analysed the data through the correlational analysis method. An outstanding limitation of the study was lack of sources to collect a chronological set of climatic data.

The research findings point out that Nairobi experiences high rainfall of approximately 728mm, an average mean temperature of 20.9 °C and moderate humidity of 69.4%. While these have little impact on mass timber structures, Nairobi's high ultraviolet radiation of 13.75 UVI is a point of risk to the moisture content of the identified wood species. Tree species such as *Juniperus procera* with a higher lignin quantity will more likely be affected by the UV radiation. Since the solutions to protect the material from environmental damage are outside the scope of this study, further research must be done to explore solutions to adopt mass timber as a material for the climate of Nairobi.

2. Literature Review

2.1. The Climate of Nairobi

The climate of Nairobi is influenced by its location: to the east of the Rift Valley, at an altitude of 1800m above sea level. Its climate is categorised as modified equatorial climate (Makhoka and Shisanya, 2010) because of its temperature and rainfall characteristics. Through two rainfall seasons, the city receives slightly more than 610mm of rainfall (310mm during the long rain season from March to May and the remaining Exploring the Feasibility of Mass Timber Use in East Africa: The Effect of Nairobi's Climate on Mass Engineered Timber Structures.

200mm from November to December during the short rain season). It however experiences a dry period between June and October (Aardenne, 2017). Ng'ang'a (1992) illustrates that the rainfall received in Nairobi is influenced by the Inter Tropical Convergence Zone (ITCZ). Nairobi experiences an average of 19°C throughout the year (Makhoka and Shisanya, 2010) with the maximum temperature varying by approximately 6°C and the minimum at 5°C. The temperature is highest from January to March at a maximum of 27.5°C and lowest in June to August at 22.5°C. The minimum daily average temperature coincides with the rainfall pattern whereby March to May (long rains) and November to December (short rains) experience the highest night-time temperature at 15°C and 14.5°C respectively (Aardenne, 2017).

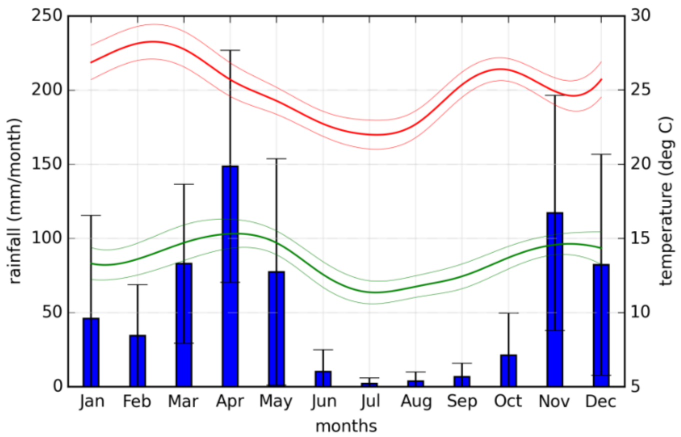

Figure 1: Graph indicating the average rainfall and temperature of Nairobi from 1981 to 2010
(Aardenne, 2017)

Nairobi's relative humidity is at a high of 80% in the morning and a lower value of 40% during the day, mostly in the afternoons (Makhoka and Shisanya, 2010).

The sunshine duration of Nairobi varies between four and nine hours per day (Makhoka and Shisanya, 2010) with a mean radiation of 8 hours. The annual solar insolation of Nairobi is estimated to be 2100 kWh/m2 which increases from zero just before sunrise and gets to the maximum level during the afternoon hours and back to zero after sunset. There is little variability in the daily solar insolation in the city ranging from 3kWh/m2/day to 7kWh/m2/day (Wasike *et al.*, 2014).

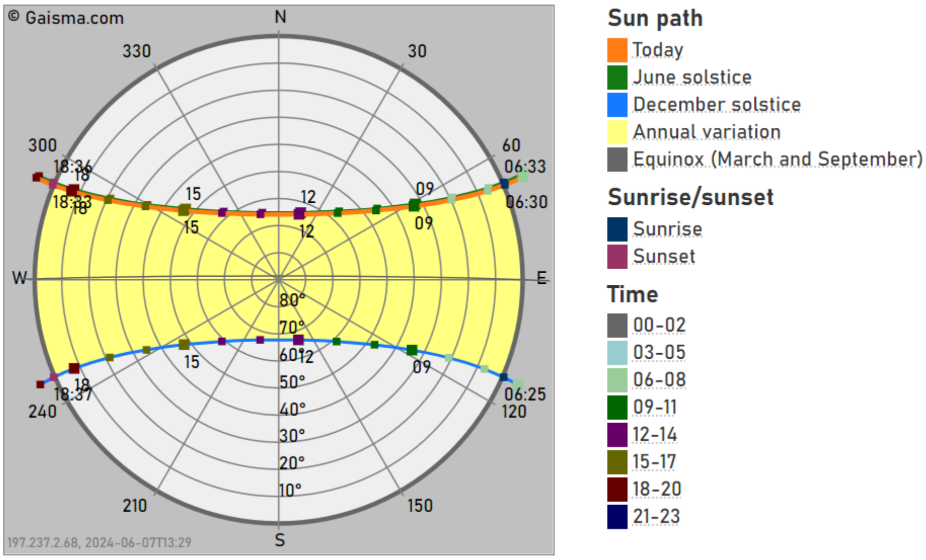

Figure 2: Nairobi's sun path diagram (Tukiainen, 2024)

Within these climatic conditions, certain tree species are grown, that can be used for MET production. The Kenya Forestry Research Institute (KEFRI) has outlined the main tree species being grown commercially as: *Pinus patula*, *Cupressus lusitanica*, Eucalyptus, *Grevillea robusta* Casuarina, and *Melia volkensii* (KEFRI, 2021). Like Kenya, Tanzania commercially grows both *Pinus patula* and *Grevillea robusta* among others (Tanzania Ministry of Natural Resources and Tourism, 2017). In Uganda, pine and eucalyptus are also the most widely grown simply because in commercial plantations, they grow well (Uganda Ministry of Water and Environment, 2007).

2.2. Mass Engineered Timber and its Characteristics

Mass timber borrows its characteristics from raw timber, which is known to be affected by natural climatic conditions. Cellulose and hemicellulose are the components responsible for the hygroscopic nature of wood. This is because they have a high hydroxyl (-OH) content (Ayanleye *et al*., 2021). The hygroscopic nature of wood and its ability to wet faster than it dries (Wang et al., 2018) creates a point of concern for timber. As a building material, care must be exercised specially to avoid reducing moisture content below the required average. The bending and compression strengths of wood increases up to a certain amount of reduction of moisture content (Kherais, *et al.,* 2020). Kherais *et al*., (2020) highlight that the conditions that affect the growth of mold are moisture present in the atmosphere and the temperature. Exposure to water from precipitation can cause increased moisture content resulting in unmet building regulations due to the growth of mold (Olsson, 2020). Proper management of moisture for structures built using timber ensures longer life spans and ensures easier maintenance. While moisture management is well understood for light timber structures, the same is yet to be determined for mass timber. Shirmohammadi (2021) points out that the wetting and drying durations for mass timber structures is yet to be fully determined.

Mass timber is timber that has undergone manufacturing through treatments application and gluing, for a high-strength construction material. Polyurethane (PUR) is the most common adhesive and has been used in both CLT and Glulam (Ayanleye *et al*., 2023). Adhesives used in MET must have a high heat resistant character. Preservatives are used in wood as a technique to increase the durability of timber while maintaining an optimum level of performance by preventing attacks by microorganisms. The two newer copper-based preservatives currently in the market widely used in moisture control are preferred for their affordability and high protection levels. These are micronized copper azole (MCA) and Copper-azole type C (CA-C) (Ayanleye, *et al*., 2021). However, wood preservation and modification can alter the bonding of the adhesive at different levels in the wood. This can change the wettability of the wood, alter the spread of the adhesive, and reduce penetration. Eventually, the cure rate of the adhesives is compromised leading to increased rates of delamination (Ayanleye *et al*., 2023).

Figure 3: Image of cross laminated timber panel that has undergone gluing and treatment.

3. Research Methodology

The study employed the positivism research philosophy since the researcher was independent of the study and had no influence on the data collected on the climate of Nairobi and the chosen wood species. While this study does not exclusively analyse and use numerical data; it has systematically collected data to establish any patterns and derive relationships between and among variables. Thus, it has adopted the quantitative research approach. However, in some instances, there is some qualitative data gathered, resulting in an overall mixed method. The causal-comparative design chosen highlights the relationship between climate as the independent variable and mass timber as the dependent variable. It seeks to find out if any of the two variables are dependent on the other. The non-probability – judgement sampling – method was used to identify samples relevant to the study. The research population comprised all the tree species that are currently used in the manufacturing of mass timber: gymnosperms (softwoods) and angiosperms (hardwoods). To select the sample, the species that are used for MET and are grown within the region were identified. The region in reference is East Africa: Kenya, Uganda and Tanzania. Due to time and research constraints, this study used only secondary data gathering processes. The data was gathered largely from various online sources and libraries that are reliable and contain verifiable information such as ScienceDirect, ProQuest, and website for institutions. Physical libraries and repositories in Nairobi were also used. Correlation analysis was used to evaluate any relationship between climate and MET and the potential effects. The climate data gathered was not in chronological order, but the researcher attempted to align the climatic conditions to similar years.

4. Findings and Discussion

4.1. The Location and Climate of Nairobi

The geographic location of Nairobi has an influence on its climate. Located to the eastern side of the Rift Valley, Nairobi is at a high altitude of approximately between 1450 and 1900 metres above sea level (Otiso, 2012). It is the capital city of Kenya, located approximately 140 km south of the equator and 483 km west of the Indian Ocean. Its coordinates are: 1.2921° South and 36.8219° East covering an approximate area of 696.1 km2. It is strategically placed at the southeastern edge of Kenya's agricultural land. While it falls within the tropical climatic conditions, its more precise description is modified equatorial climate.

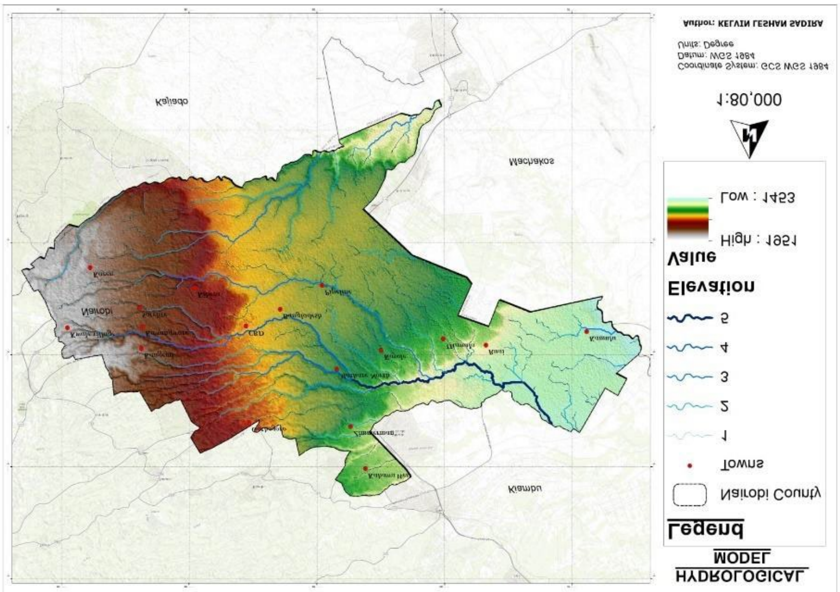

Figure 4: Hydrological map of Nairobi

The western side of the city is cooler and better drained while the eastern side is hotter due to its lower altitude characterised by poor drainage (Otiso, 2012). The hydrological map below is a visual representation of the altitude of Nairobi. The amount of rainfall experienced in Nairobi is influenced by the movement of the Intertropical Convergence Zone (ITCZ) whereby when it moves to the south, the city receives its long rains between March and April and when in the north, it receives its short rains in November and December. The temperature is influenced by the amount of rainfall received while both the precipitation and temperature influence the humidity and ultraviolet radiation experienced in the city. The table below illustrates the mean monthly and annual climatic conditions of Nairobi.

Table 1: Table indicating the mean annual rainfall, temperature, humidity and ultraviolet radiation of Nairobi

MONTH	RAINFALL (mm)	TEMP (°C)	HUMIDITY (%)	UV (UVI)
January	40.0	21.48	65.0	15
February	45.0	22.42	57.5	16
March	70.0	22.66	63.5	16
April	157.5	21.31	75.5	16
May	110.0	19.99	76.5	13
June	27.5	19.36	74.0	11
July	11.0	19.26	72.0	11
August	12.0	19.92	68.0	13
September	22.5	21.08	63.0	14
October	42.5	21.82	65.0	14
November	115.0	20.48	78.0	14
December	75.0	20.63	74.5	13
AVG	**60.6**	**20.9**	**69.4**	**13.75**

4.2. Characteristics of Tree Species used for Mass Engineered Timber

This study focused on and analysed the characteristics of specific (see **Table** below) gymnosperm tree species except for eucalyptus (an angiopserms found in the myrtaceae family). These species were selected for two reasons: they are the most widely grown and used tree species from in Kenya (Omondi *et al*., 2020) and they can be used for MET production.

Table 2: Table illustrating the moisture content, density and lignin content in the chosen tree species common in Kenya and can be used for MET production

Genus	Species	Equilibrium Moisture Content (%)	Density (kg/m3)	Amount of lignin (%)
Pinus	*Pinus patula*	12	490	26-29
Cedrus	*Juniperus procera*	12	480	47.92
Cupressus	*Cupressus lusitanica* Miller	12	446	30-31
Eucalyptus	*Eucalyptus saligna*	12	730	27.0

Since wood in its various forms is hygroscopic in nature, it is expected that in conditions such as availability of stagnant and / or moving water in any amount the timber will absorb the water. Water absorption by timber is inversely related to its density – the lower the density of the timber species, the higher the water absorption. The reverse is true. This can be illustrated in a simple line graph as shown below.

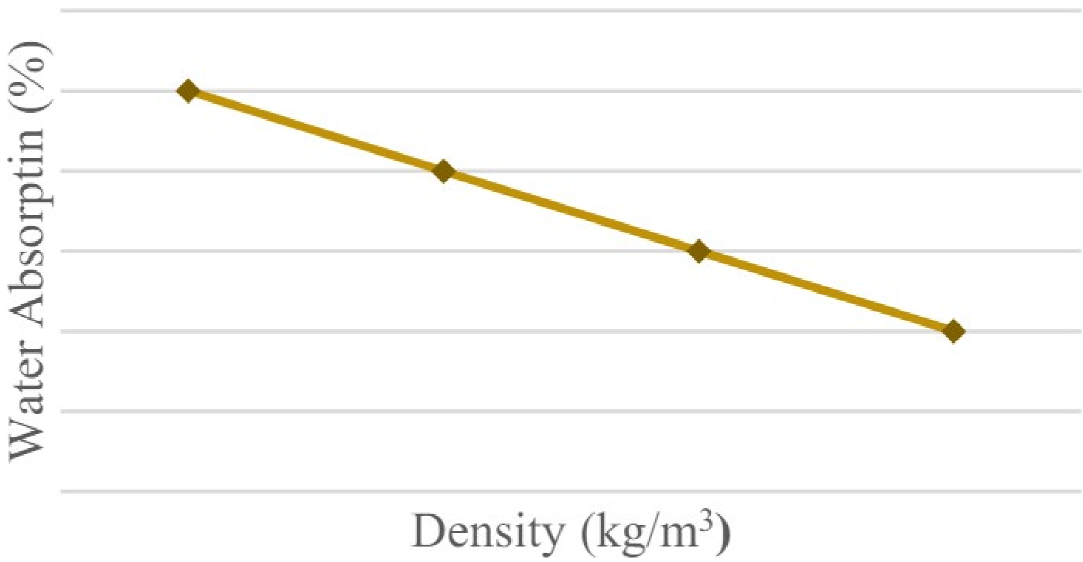

Figure 5: Graph indicating the relationship between wood density and water absorption

To obtain high quality MET, raw timber undergoes a manufacturing process that ensures a high structural strength and protection from damage by environmental factors. For maximum impact, the timber planks are first treated using preservatives such as Copper chrome arsenate (CCA) and boron-based disodiumoctaborate tetrahydrate (DOT) and are thereafter glued using adhesives such as polyurethane (PUR) and phenol-resorcinol formaldehyde (PRF). Ayanleye *et al*., (2023) advise that treatment is done before gluing rather than doing a post-treatment intervention since it may be impossible to treat large sections of the timber after gluing and lamination.

4.3. Potential Effect of Nairobi's Climate on MET

As shown, tree species such as *Eucalyptus saligna* have a high density of 730 kg/m3, meaning that they have lower water absorption rates unlike other species such as *Cupressus lusitanica* Miller which has a lower density of 446 kg/m3. Waterproofing measures have to be used during the two rainy seasons (March – May & November –

December) while using this material. Additionally, MET structures built to the west of the city should include both species with higher densities and higher moisture control measures.

Since Nairobi's temperature is well below 40°C, the adhesives in MET may not be influenced by the temperature. It is only MET using PUR adhesive that will be affected by temperatures above 40°C. The timber loses stiffness and resistance, exuding characteristics of plastic failure. Its mechanical properties decline at a linear proportion to increase in temperature (Verdet, 2016).

However, the high ultraviolet radiation level in the city is a risk to MET structures. Since lignin in wood is a UV absorber, accommodating wavelengths between 250 and 400 nm, mass timber structures to be built in Nairobi will experience UV damage. MET made of species such as *Juniperus procera* with a lignin content of 47.92% will experience more UV damage. Wood is a photosensitive material and will degrade over a certain duration of exposure to both UVB and UVA rays. Mass timber exposed to high levels of UV radiation will eventually degrade, characterised by cracks and changes in colour. It can also look stringy, and the tactile texture becomes rough. The colour change is a result of depolymerised lignin and cellulose present in the timber. Water then leaches away these two components, leaving the timber grey in colour. To protect the material, adequate treatment options should be employed.

5. Conclusion and Further Research

The aim of this study was to evaluate whether Nairobi's climate has any impact on structures made of mass engineered timber. The study has revealed that Nairobi's climate may have an impact on MET structures. Because Nairobi experiences an average rainfall amount of 728.0 mm and a relative humidity of almost 70%, mass timber structures may absorb this moisture and alter the moisture content. If not adequately treated, the alteration in MC will compromise the compressive strength of the MET. MET structures in Nairobi may also face compromised compressive strength due to exposure to high UV radiation levels. However, the extent of risk and potential decline in the strength was not covered in this study, and provides with an opportunity for further research.

Future research may be undertaken to identify the suitable solutions to protect MET structures from UV radiation damage and moisture caused by humidity and rainfall, especially in the months of April to June and November to December. Additionally, further research regarding the type of timber (or tree species) that is most suitable for MET use in the city. As much as there are species currently being widely grown within the country for several uses, there should be more research as to which tree species should be explored, specifically for MET development.

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