Decay Performance Modeling of Historic Timber Roof Structures of Amantubillah Palace in Mempawah, Indonesia

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Abstract. Durability problem is a usual shortcoming of utilizing timber as a construction material. After exposed to the weather in decades, the historic timber building often experienced a severe deterioration process. Amantubillah Palace, as Mempawah Sultanate’s inheritance, also suffers from this process. The repair and replacement action are needed to preserve this legacy from the past. Thus, it is essential to know the remaining service life of the building. The calculations of decay depth were carried out by utilizing the Australian CSIRO model incorporating the parameters which are related to the Indonesian tropical climate. From the calculations, it is obtained that the decaying process will reach the centre of the cross-section in 83 years. It is recommended that repair or replacement action should be taken immediately.

1. Introduction
Amantubillah Palace is located at Mempawah Regency, West Kalimantan Province, Indonesia. It was first built during the reign of Gusti Jamiril, who has the title Panembahan Adi Wijaya Kesuma (1761-1787). He was the 3rd Sultan of Mempawah Sultanate. Amantubillah Palace caught fire in 1880. It was rebuilt and in function again on November 2nd, 1922, when Gusti Muhammad Taufik Accamaddin (1902-1943) reigned Mempawah.

The Palace is a timber building made of local material. In the past, timber is abundant and easily found in the tropical forest of Kalimantan. Many timber species have excellent durability properties as a construction material. Due to this reason, most of the historic building in West Kalimantan is timber building.

The common drawback of using timber as a construction material is its durability issues. The preservation actions such as repair and replacement of the main building elements should be done at the right time. Thus, it is vital to investigate the occurring deterioration process and predict the building’s remaining service life. Numerous research has been done in simulating the service life of the timber structures. The combination of durability with strength parameter had been offered by Van de Kuilen [1], building physics hygrothermal model had been studied by Viitanen et al., [2], and damage functions coupled with structural and hygrothermal model had been proposed by Nofal and
Kumaran[3]. Corrosion of metal fasteners embedded in the solid wood model had been simulated by Zelinka et.al [4], and the decaying process model combined with hygrothermal analysis was studied by Saito at.al [5]. Massive and extensive field and laboratory research in Australia had been shared by Wang at.al[6] and MacKenzie at.al[7]. A dose-response performance model had been shown by Bornemann at.al [8], and wood durability and preservation in European Standardization was presented by Kutnik at.al[9]. A dose-response performance using the factorization approach was introduced by Meyer-Veltrup at.al[10], and a decay model incorporating Indonesian tropical climate parameters was presented by Prabowo&Hilmy[11].

The durability model introduced by MacKenzie at.al [7] will be addressed due to limited timber durability research in Indonesia. The regional nearness is one of the reasons to utilize the model. The parameters included in the model are Timber durability class and species of local timber, temperature, relative humidity, and degradation mechanism.

2. Methodology

The decay performance of roof structures will be evaluated by taking the CSIRO (Commonwealth Scientific and Industrial Research Organisation). It is based on the Australian climate condition[7]. The decay above ground condition will be addressed for the model. The roof structures’ components will be measured for their thermo-hygic properties. As a comparison, local relative humidity and temperature data from the nearest weather station will be collected and plotted. The dimension of the building and roof structures taken from field measurements will be given.

2.1. The model of decay depth

The model of decay depth constitutes two different components. The first component describes the decay depth that occurred before and at the time when deterioration initiates. After the initiation of deterioration, the second component of the decay depth model will be used.

The decay depth model includes two controlling parameters: a decay lag (\(t_{\text{lag}}\)) and a decay rate (\(r\)). A decay lag is measured in a unit of years where a decay rate is quantified in a unit of mm/year. All related parameters to decay depth model are expressed in equation (1) to equation (5), where \(d(t) = \) decay depth after \(t\) years of installation, \(d(0) = \) decay depth at the initiation time, \(k_{\text{wood}} = \) wood parameter, \(k_{\text{climate}} = \) climate parameter. The model of decay depth is demonstrated in figure 1.

\[
\begin{align*}
    d(t) & = \begin{cases} 
    ct^2 & \text{if } t \leq t_{\text{lag}} \\
    (t-t_{\text{lag}})r & \text{if } t > t_{\text{lag}} 
    \end{cases} \\
    t_{\text{lag}} & = t_{\text{lag}} + \frac{d_0}{r} \\
    c & = \frac{d_0}{t_{\text{lag}}}^2 \\
    t_{\text{lag}} & = 8.5r^{-0.85} \\
    r & = k_{\text{wood}}k_{\text{climate}} 
\end{align*}
\]
2.2. Local relative humidity and temperature

The relative humidity and temperature data were obtained from the nearest weather station. The data were recorded by Mempawah Climatological Station, Mempawah Regency, Indonesia. They are collected from the year 2004 until 2019 to simulate the weather condition in July[12]. The relative humidity (RH) and temperature (T) are illustrated in figures 2 and 3.

![Figure 2. RH in july from 2004 to 2019.](image1)

![Figure 3. T in july from 2004 to 2019.](image2)

2.3. The roof structures

The roof structures are in the form of timber trusses. The trusses are made of two local timber species: Belian (ulim) (Botanical name: *Eusideroxylon zwageri*) and Bangkirai (Botanical name: *Shorea laevis*). These two species are well-known for their durability against the weather. They are classified as durability class 1 and durability class 2, respectively. The cross-section of the truss is rectangular with dimension 8 cm x 14 cm. The truss members are jointed with a wooden dowel. The roof truss can be seen in figure 4.

The main building width and length are approximately 36 m x 47 m. The main components of the building are made of Belian. The main building consists of the throne room, main rooms, and the porch. The plan and front view of the building can be noticed in figure 5.

![Figure 4. The roof truss.](image3)
2.4. The thermo-hygic evaluations

The thermo-hygic evaluations of the roof structures’ components were carried out by utilizing a humidity-temperature digital instrument (YK-2001 TM type, Lutron, Taiwan), as shown in figure 6. The measurements referred to ASTM F2420-05 [13]. It is conducted three times in one day: morning (8 am to 10 am), noon (11.30 am to 1.30 pm), and afternoon (4 pm to 6 pm). The measured parameters are graphed in figure 7 and figure 8.

3. Results and Discussions

The decay depth calculations have been performed to simulate the service life of the roof structures. The assumed decay depth initiation is 5 mm under the surface of roof structures’ cross-sections. The model input parameters are $k_{\text{wood}} = 0.5$ (ulin species), $k_{\text{wood}} = 0.62$ (bengkirai species), $k_{\text{climate}} = 0.4$ (the least hazardous zone), $k_p = 3.5$ (ulin, painted timber), $k_t = 1$ (thickness 80 mm), $k_w = 1.1$ (width 80 mm), $k_n = 1$ (no connector), $k_{g1} = 0.3$ (non-contact), $k_{g2} = 2$.

The depth decay calculation during the building service life can be seen in figure 9. It illustrates the $d(t)$ vs. $t$, especially for building service life, which is almost 100 years. The graph shows that a decay rate ($r$) = 0.46 mm/year for Belian and $r = 0.57$ mm/year for Bangkirai. The decay lag ($t_{\text{lag}}$) is equal to...
16.389 years for Belian and 13.648 years for Bangkirai. These values mean the initiation of deterioration in 16 years for Belian and 13 years for Bangkirai right after the building was built. The first component of the graph shows a parabolic curve referred to as equation \( dt = ct^2 \). A relatively linear curve is simulated by the second component of the graph under the equation \( (t - t_{lag})r \).

The initiation of \( t_{lag} \) can be well observed in figure 10. It is graphed to show the initiation of \( t_{lag} \) more clearly. The graph shows that after 40 years, the decay depth reaches 11 mm for Belian and 15 mm for Bangkirai. The decay depth will reach 40 mm in 100 years for Belian and 83 years for Bangkirai.

![Figure 9. The decay depth during the building life.](image)

![Figure 10. The initiation of \( t_{lag} \).](image)

### 4. Conclusion
The demand for the simple and practical formulation of service life prediction of a historic building is increasing. It is needed to determine the repair or replacement time of the deteriorated building components. The calculations of decay depth give that a decay rate \( r = 0.46 \) mm/year for Belian and \( r = 0.57 \) mm/year for Bangkirai. The decay lag \( (t_{lag}) \) is equal to 16.389 years for Belian and 13.648 years for Bangkirai. The decaying process will reach the centre of the cross-section in 100 years for Belian and 83 years for Bangkirai. This condition will risk the stability and safety of the roof structures. It is advised that the repair action, such as adding area or replacement of the existing cross-section, should be implemented.

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