Service life prediction of historic timber-framed structures of the Kadariah Palace in Pontianak, Indonesia

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Abstract. Durability is a significant subject when using timber in construction, especially for the historic building aged hundreds of years. The heritage building should be well preserved as a national identity and also as a legacy of humanity. Thus, it is crucial to understand the building residual service life. It can be used to decide the time when the repair or replacement has to be done. The decay depth calculation shows that the main structural elements will reach the center of the cross-section (75 mm) in 150 years (around the year 1920). The condition threatens the stability and safety of the building. The additional width and thickness to the existing structural elements cross-section and the application of weather shield paint on the surface of structural elements periodically in recent times proved to be effective in maintaining the building remain to stand.

1. Introduction

The existing historic building is essential to be well preserved as a national identity and a legacy of humanity. Indonesia, a country rich with cultural heritage, has numerous historic timber buildings. The most ordinary types of these buildings are Sultanate’s Palaces and Old Mosques. One of the buildings still function is Kadariah Palace. It is a Sultanate Palace established in 1771 by Syarif Abdurrahman Al-Qadri, the first Sultan of Pontianak Sultanate. The Sultanate was located at the Kapuas River's mouth in today’s Indonesian province of West Kalimantan.

Durability is still an issue when using timber in construction. Furthermore, the historic buildings aged hundreds of years usually suffer from several types of degradation mechanisms. This condition indeed threatens the service life of the building. Therefore, it is fundamental to identify the existing building's residual service life to find out the necessity of repair or replacement. There are much research has been done to model the service life of timber structures. A combined model of damage model and strength reduction model can be found in [1], a new tools for evaluating the durability and service life of wooden products and a preliminary European wood decay risk level map is provided in [2], and details of biological damage functions implemented in the damage function module of IRC’s durability assessment system are presented in [3]. a combined hygrothermal/corrosion model for simulating the corrosion of metals embedded in wood is simulated in [4] and a quantitatively predict both hygrothermal conditions within the building envelopes and the progress of decay in wood structures under variable conditions is modelled in [5]. A research in [6] and [7] gave a long duration
and enormous field and laboratory research and experience in the laboratory and the field on the decay progress of timber in Australia. Besides, a dose–response performance model considering wood moisture content and temperature as key factors for fungal decay is used in [8]. An effort of enhancing durability and performance classification of wood products in construction in Europe is discussed in [9], and an instrument for design and service life prediction of timber structures is developed in [10]. The CSIRO decay model with Indonesian tropical climate input parameter is studied in [11]. The timber structures durability research in the Indonesian tropical environment is still minimal. Thus, it is decided to adopt one of the internationally notable models in this research. It is a timber durability model developed in [7]. This model is chosen considering the geographical proximity of Australia to Indonesia. This geographical issue is assumed to influence several parameters involved in the model, among other temperatures, moisture, mechanisms of degradation, and wood species. Parameters such as durability class and Indonesian timber species will be explained to address the topic of tropical climate condition in Indonesia.

2. Methodology

The predicted decay model is taken as a basis of service life prediction of the Kadariah Palace. This model is adopted from the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO). The predicted model in this paper considers the condition for decay above ground. The macro-climate of Pontianak’s city will be reported, and the field hygro-thermal measurements will be carried out. The data regarding the Kadariah Palace’s main structural elements will also be addressed.

2.1. Predicted Decay Model

The predicted decay model consists of two essential parts. The first part is related to the decay depth condition and right at the time when the decay begins. The second part deals with the decay depth progress for the time after the beginning of the deterioration. This model has two central parameters: a lag of decay (tlag) expressed in years and a rate of decay (r) expressed in mm/year. The component of the mathematical equation of the model can be written in the form of equation (1) until equation (5).

\[d(t) = \begin{cases} \frac{ct^2}{r} & \text{if } t \leq t_d \\left( t - t_{lag} \right)^r & \text{if } t > t_d \end{cases}\]  

(1)

\[t_d = t_{lag} + \frac{d_0}{r}\]  

(2)

\[c = \frac{d_0}{t_d^2}\]  

(3)

\[t_{lag} = 8.5r^{-0.85}\]  

(4)

\[r = k_{wood}k_{climate}k_pk_wk_nk_g\]  

(5)

where \(d(t)\) = depth of decay after \(t\) years of putting in place, \(d(0)\) = decay depth at the starting time, \(k_{wood}\) = wood parameter, \(k_{climate}\) = climate parameter, \(k_t\) = thickness parameter, \(k_w\) = width parameter, \(k_n\) = fastener parameter, dan \(k_g\) = geometry parameter. The model can be depicted in figure 1.
2.2. Pontianak city macro-climate

The macro-climate data presented here are relative humidity and temperature. These two data are based on the climate data recorded by Meteorological, Climatological, and Geophysical Agency (BMKG) in Supadio International Airport (IATA: PNK, ICAO: WIOO), West Kalimantan, Indonesia. These data obtained from July 2004 until July 2019 [12]. The data plotted, as shown in figure 2 and figure 3.

Figure 2. Relative Humidity (RH) in July (2004-2019).

Figure 3. The temperature (T) in July (2004-2019).

2.3. The Kadariah Palace’s main structural elements

The studied building's main structural elements are made of Belian (ulin) (Botanical name: *Eusideroxylon zwageri*). This Indonesian local wood species is famous for its robustness against the local climate. It is classified in durability and strength class 1. The main structural frame of the building consists of a column and beam system and floor system. The cross-section is rectangular with dimensions 15 cm x 15 cm. The columns can be divided into the primary main supporting column and the secondary supporting column. The building plan, building section, and front view of the Kadariah Palace can be seen in figure 6.
2.4. The building thermo-hygric evaluation

The measurements are conducted by means of the RH-T instrument (YK-2001TM type, Lutron, Taiwan), Figure 5. It is prepared according to ASTM F2420-05 [13]. The temperature (T) and relative humidity (RH) measurements were carried out for exterior and interior columns. The measurements were conducted three separate times, in the morning (from 7 am until 9 am), noon (from 11.00 am to 1.00 pm), and in the afternoon (from 3 pm to 5.30 pm). It is done in July 2020. The results can be seen in figure 5 until figure 8.

3. Results and Discussions

The computation of predicted service life of Kadariah Palace has been done for the main structural elements. The depth of decay is concluded to take place at the beginning at 5 mm deep beneath the surface of the timber structural elements. The input parameters for the model among others: $k_{\text{wood}} = 0.5$
(ulin species), $k_{\text{climate}} = 0.4$ (the most hazardous zone), $k_p = 3.5$ (ulin, painted timber), $k_t = 1$ (thickness 150 mm), $k_w = 1.3$ (width 150 mm), $k_a = 1$ (no connector), $k_{g1} = 0.3$ (non-contact), $k_{g2} = 2$.

**Figure 9.** depth of decay, $d(t)$, during building’s life

**Figure 10.** depth of decay, $d(t)$, at the lag of decay

Figure 9 plotted the depth of decay, $d(t)$ versus the time variable ($t$) during the entire building’s service life. The resulted graph show a rate of decay ($r$) = 0.56 mm/year and lag of decay ($t_{\text{lag}}$) = 13.914 years. The graph first portion demonstrates a parabolic arc according to the equation $dt=ct^2$. Meanwhile, the second part of the graph gives a straight line based on the formula ($t-t_{\text{lag}}$). Figure 10 illustrated the depth of decay, $d(t)$ versus the time variable for 50 years period. It is graphed to simulate the occurrence of lag more clearly. It is interesting to notice that the rate of decay will reach the midpoint of the cross-section elements in 150 years.

### 4. Conclusion

It is quite demanding some more practical and straightforward formulation of the service life of historic timber buildings in Indonesia. It is required to decide the time when the repair or replacement has to be done. The carried out simulation of the depth of decay for Kadariah Palace shows that the main structural elements will reach the mid cross-section in 150 years (around the year 1920). This condition indeed threatens the stability and the safety of the building. The fact that the building remains to stand nowadays is due to the additional width and thickness of the existing structural elements cross-section. The other reason is due to the application of weather shield paint on the surface of structural elements periodically in recent times.

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