ATLANTIS PRESS
Advances in Engineering Research, volume 156
18th International Conference on Sustainable Environment and Architecture (SENVAR 2018)

The Use of Decay Model to Predict Service Life of Indonesian Historic Timber Buildings

Herry Prabowo
Department of Architecture
Politeknik Negeri Pontianak
Pontianak, Indonesia
prabowoherry@yahoo.com

Mochamad Hilmy
Department of Architecture
Politeknik Negeri Pontianak
Pontianak, Indonesia
mhimys@gmail.com

***Abstract*—Indonesia, one of the tropical countries in the world, is rich with cultural heritage. Almost every tribe in Indonesia has its own traditional timber house. Besides the traditional houses, the most common type of historic timber buildings in Indonesia is Sultanate's Palace or perhaps Old Mosque. These buildings usually aged hundred of years and required to be kept lasting as national identity. It is quite essential to know their remaining service life as one of consideration in the conservation action plan. The main problem of using wood as a construction material is its durability. This durability aspect is closely related to degradation mechanisms. Timber degradation can be classified as mechanical, physical, chemical and biological degradation. The combination of biological degradation and a mechanical load is the essential parameter for service life modeling so far. The prediction of service life is conducted by using Decay Model from Australian CSIRO (Commonwealth Scientific and Industrial Research Organisation) Sustainable Ecosystems for decay above ground mechanism. The model takes into account various aspects of the wood parameter, climate parameter, paint parameter, thickness parameter, width parameter, connection parameter, and geometry parameter. The opportunity to simulate the service life based on the Indonesian circumstances has been demonstrated in this paper.**

Keywords— historic timber building, service life, decay model, Indonesian environment

I. Introduction

Indonesia, which is known as the largest archipelagic country in the world, consists of around 17000 islands with hundreds of tribes [1],[2]. This thing makes Indonesia, one of the tropical countries in the world, rich with cultural heritage. Almost every tribe in Indonesia has its own traditional timber house. Besides tribal dwellings, the most common type of historic timber buildings in Indonesia is Sultanate's Palace or perhaps Old Mosque. These buildings usually aged hundred of years and required to be kept lasting as national identity. It is quite crucial to know their remaining service life as one of consideration in the conservation action plan. One of the historic building that still in use until today is Jami Mosque of Pontianak, which also well-known as Sultan Syarif Abdurrahman Mosque. This building located in the city of Pontianak, West Kalimantan, Indonesia. It is built on October 23rd, 1771 and still in function.

The main problem of using wood as a construction material is its durability. This durability aspect is closely related to degradation mechanisms. Timber degradation can be classified as mechanical, physical, chemical and biological degradation. The combination of biological degradation and a mechanical load is the essential parameter for service life modeling so far. The prediction of service life is conducted by using Decay Model from Australian CSIRO (Commonwealth Scientific and Industrial Research Organisation) Sustainable Ecosystems for decay above ground mechanism [3].

II. Literature Review

The basis for the prediction of the service life of Indonesian historic timber buildings presented in this paper established based on the research undertaken by Australian CSIRO (Commonwealth Scientific and Industrial Research Organisation) Sustainable Ecosystems for decay above ground mechanism. The model considers the attack mechanism, wood parameter, climate parameter, paint parameter, thickness parameter, width parameter, connection parameter, and geometry parameter. The explanation about the model can be seen below.

A. The Attack Mechanism

The deteriorating fungi attack mechanism is depicted in Fig. 1 till Fig. 5, which is based on the model given by [4]. Fig. 1. demonstrates the distribution of moisture within the cellular structure of wood. For moisture contents up to the fiber saturation moisture content (about 30%), the wetness is absorbed into the cell walls, and decay is minimum because the decay fungi do not have enough suction strength to access the moisture. Higher than this value, the wetness is in a free-form, easily accessible to the decay fungi, and as a consequence, decay rapidly proceeds as shown in Fig. 2. When the cellular lumens are fulfilled by at least 80% of water, there is insufficient oxygen for the decay fungi to endure and accordingly decay ceases.

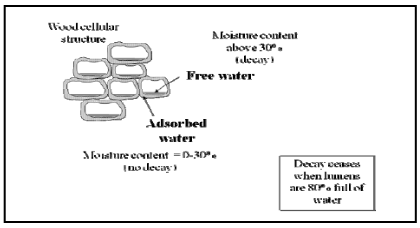

Fig. 1. Definition of moisture in timber

Fig. 3. shows a typical attack scheme for exposed timber construction. Typically a tiny slit or gap in a covering member will suck in rainwater through capillary action and

soak it into an underlying wood-based substrate. This moisture cannot fade away through the narrow opening. It must do so through at the other face of the wood-based substance. If it can be done quick enough, then it collects in the wood-based material where the wetness may pass the 30% mark, and deterioration will commence. The rotten wood substrate itself then forms a basin in which substantial moisture can be held.

Fig. 4. depicts the attack scheme for the case of an exposed timber element. Here it is vital for wood first to develop a surface check through mechano-sorptive effects. Once a sufficiently deep inspection has expanded, it will draw rainwater and generate an impermanent well at the base of the check. Eventually, this water may be sufficient to commence decay. As the pocket of decay increases in size, it holds more water and leads to raised decomposition for each rainfall episode.

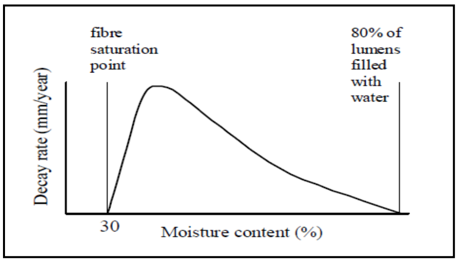

Fig. 2. Schematic model of moisture content on the rate of decay

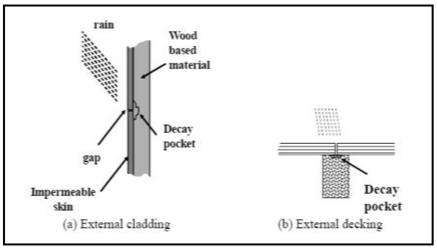

Fig. 3. Model of the role of a gap on decay

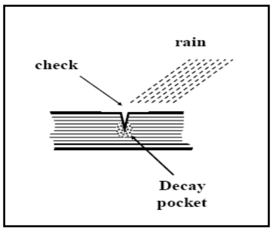

Fig. 4. Model of scenario for the decay of exposed members

B. Prediction Model

An underlying hypothesis for this model is that progress of decay depth with time in a timber element can be approximated by an idealized bilinear relationship characterized by a decay lag and a decay rate. Herein the notations r and tlag are intended to denote median value estimates. A graphic representation of this connection is shown in Fig. 5. Thus the decay depth after t years of installation is expressed as follows.

C. Decay Rate

Decay rate, r, is assumed to be the product of multipliers that take into account the effects of material, construction, and environmental factors as follows.

$$r = k_{wood} k_{\text{climate}} k_p k_t k_w k_n k_g \tag{1}$$

where k_{wood} = wood parameter; $k_{climate}$ = climate parameter; k_p = paint parameter; k_t = thickness parameter; k_w = width parameter; k_n = fastener parameter; and kg = geometry parameter.

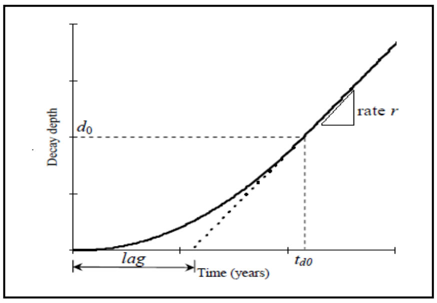

Fig. 5. Model of the role of a gap on decay

III. Methodology

There are two types of climate data presented in this paper, namely macro-climate data and micro-climate data. The macro-climate data have a role in describing the average weather condition in the city of Pontianak. Meanwhile, the micro-climate data give more detail assessment right on the surface of the studied objects. The appropriate weather parameter then used as an input parameter in the decay model to predict the service life of Sultan Syarif Abdurrahman Mosque.

A. The Macro-climate Data of Pontianak City

Macro-climate data based on records obtained from Meteorological, Climatological, and Geophysical Agency (BMKG) in Pontianak. The data include humidity and temperature parameters. The BMKG weather station is located in the complex of Supadio International Airport (IATA: PNK, ICAO: WIOO), West Kalimantan Province, Indonesia. The data were gained in July during the year 2004 until 2015 [5]. These macro-climate data presented to give insight into the general weather condition in the city of Pontianak. The graphs can be seen as follows (Fig. 6 until Fig. 7).

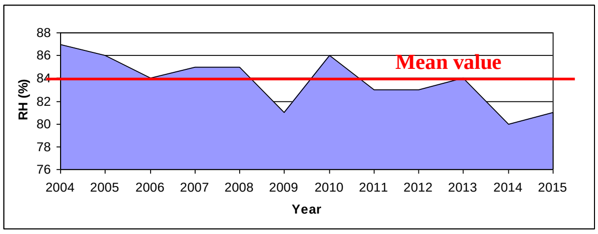

Fig. 6. Relative Humidity in July (2004 – 2015)

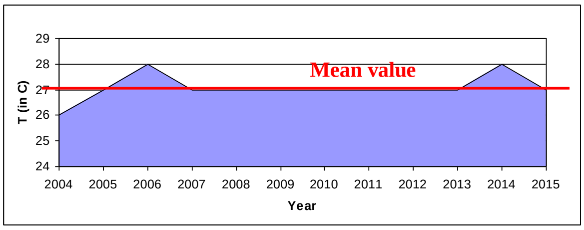

Fig. 7. The temperature in July (2004 – 2015)

B. The Main Structural Element of The Jami Mosque

The main structural elements of the examined structures are made of timber. The common timber species used for the significant building is Belian (ulin) (Botanical name: Eusideroxylon zwageri). This species is well-known for its durability against weather. According to Indonesian Timber Construction Code 1961 [6], Ulin is classified to have strength and durability class 1 [7]. It has specific gravity 1.04 [8].

The main structural elements observed consist of the foundations, columns, and the floors. All these structural elements are made of ulin. The measurements of hygro-thermal data will be focused on the columns of the structures. It is done to give a chance to differentiate between structures exposed to weather and those protected in the building envelope for aboveground building elements Fig.8 [9].

The columns connect the floor structural system and the skeletal roof system. The columns can be separated into main supporting columns and secondary supporting columns. The primary columns are located in the center of the building. Meanwhile, some of the secondary columns are laid in the perimeter of the building, and the others serve as the supporting structures of the porch. The primary columns have a round cross-section with around 60 cm in diameter and 8 m in height. The supporting columns have a rectangular shape with dimension 28 cm x 28 cm and 20 cm x 20 cm.

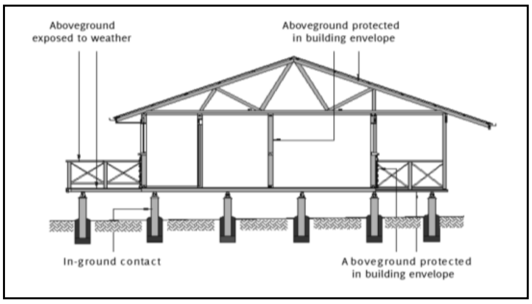

Fig. 8. Weather exposure in building

C. The Hygro-thermal Measurements

The object for temperature and relative humidity measurements is Sultan Syarif Abdurrahman Mosque. These couple data, temperature, and humidity, commonly called hygro-thermal data. The hygro-thermal data taken here are serving as micro-climate condition of the object. The Mosque is a one-story building with a rectangular shape geometric site. The length of the building is around 39 m, and the width is around 28,5 m. The front view and the plan of the building are as follows (Fig. 9).

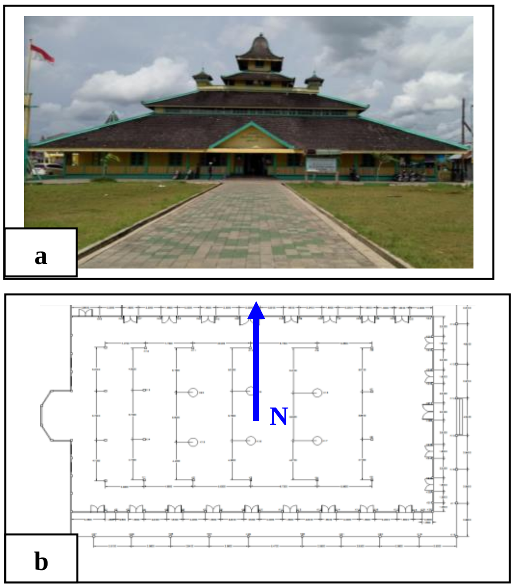

Fig. 9. (a) Jami Mosque's front view (b) Building plan with north (N) direction

The hygro-thermal measurements are conducted at all columns. The measures aim to identify any differences about temperature (T) and relative humidity (RH) between exterior (Fig. 10a) and interior columns (Fig. 10b). The measurements are performed according to ASTM F2420-05 [10]. The device used to measure is the humidity-temperature digital instrument (YK-2001TM type, Lutron, Taiwan) (Fig.10c).

The measurements were conducted in August 2018. They were measured in three durations, which were in the morning, noon, and in the afternoon. The measurements in the morning last from 8 am until 10 am, noon from 11.30 am to 1.30 pm, and in the afternoon from 4 pm to 6 pm. The data obtained were then plotted in graphs to interpret the results quickly. The figures can be seen as follows (Fig. 11 till Fig. 14).

Fig. 10. The measurement of (a) Exterior Columns (b) Interior Columns (c) RH-T Digital Instrument

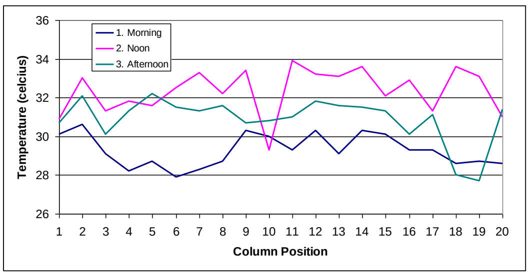

Fig. 11. The measured temperature for exterior columns

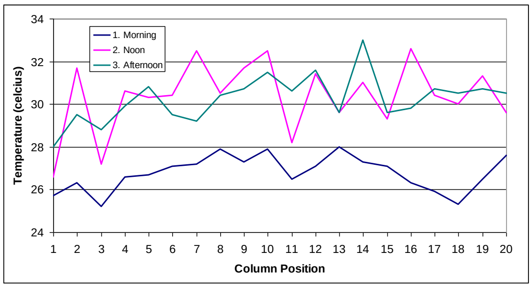

Fig. 12. The measured temperature for interior columns

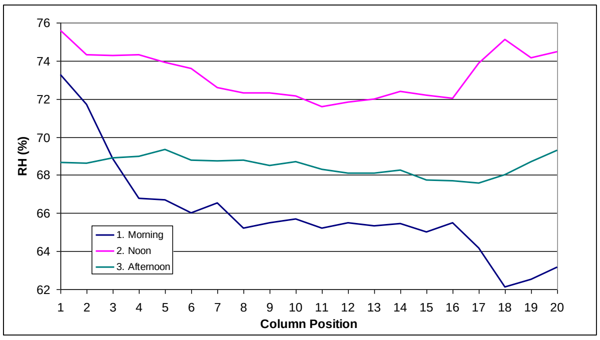

Fig. 13. The measured RH for exterior columns

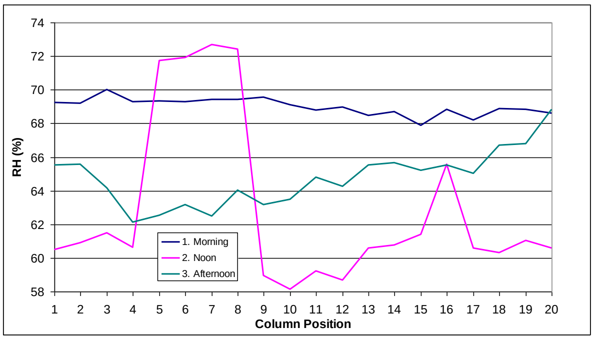

Fig. 14. The measured RH for interior columns

IV. Numerical Calculations and Discussions

The numerical calculation of predicted service life of Sultan Syarif Abdurrahman Mosque. The calculations are carried out for the building columns both for interior or exterior columns. The decay depth is assumed to occur at the first time at 5 mm deep under the surface of the timber. The inpu parameter for interior columns: k_{wood} = 0.5 (ulin species), $k_{climate}$ = 0.7 (the most hazardous zone), k_p = 3.5 (ulin, painted timber), k_t = 1 (diameter 60 cm), k_w = 1,5 (diameter 60 cm), k_h = 1 (no connector), k_{g1} = 0.3 (non-contact), k_{g2} = 6 (top-flat). The inpu parameter for exterior columns: k_{wood} = 0.5 (ulin species), $k_{climate}$ = 0.7 (the most hazardous zone), k_p = 1 (ulin, unpainted timber), k_t = 1 (diameter 60 cm), k_w = 1,5 (diameter 60 cm), k_h = 1 (no connector), k_{g1} = 0.3 (non-contact), k_{g2} = 6 (top-flat). The calculations are then plotted in graphs as follows.

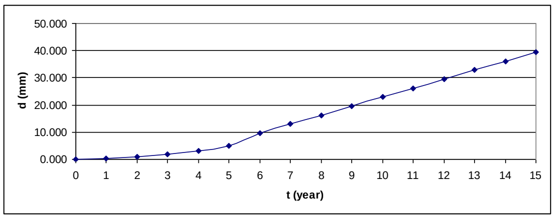

Fig. 15. Decay depth (d) vs. time (t) for interior columns

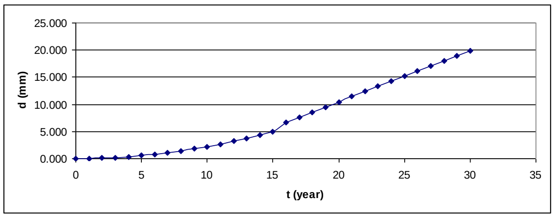

Fig. 16. Decay depth (d) vs. time (t) for exterior columns

Fig 15. simulates the decay depth (d) and the time variable (t). The graph has the decay rate (r) = 3.31 mm/year and a decay lag (t_{lag}) = 3.075 years. The first portion of the graph has a parabolic curve according to the formula d_t=ct^2. On the other hand, the second portion of the graph has a linear curve according to the formula (t-t_{lag})r. The thing that should be noticed is based on this graph the decay rate will reach the center of the structural elements that have a diameter of around 60 cm in 200 years.

Fig 16. simulates the decay depth (d) and the time variable (t). The graph has the decay rate (r) = 0.95 mm/year and a decay lag (t_{lag}) = 8.919 years. The first portion of the graph has a parabolic curve according to the formula d_t=ct^2. On the other hand, the second portion of the graph has a linear curve according to the formula (t-t_{lag})r. The thing that should be noticed is based on this graph the decay rate will reach the center of the structural elements that have diameter around 60 cm in 600 years.

V. Conclusion

The most straightforward and more practical formulation of the service life of historic timber buildings in Indonesia is quite demanding. It is due the urgent conservation action plan in some historic buildings that almost entirely decay. Besides, it is needed due to numerous historic site across Indonesia that need quick assessment. The numerical calculations done for Sultan Syarif Abdurrahman Mosque show that the building main structural elements, the columns, are in their critical decay time. Several physical tests could be done to validate the simulation results,. The non-destructive test (NDT) should be considered remembering the building age.

Acknowledgment

Authors wish to acknowledge financial support from the Indonesian Ministry of Research, Technology, and Higher Education (KEMENRISTEKDIKTI) fiscal year 2018. The assistance or encouragements from colleagues and extraordinary works by technical staffs are also gratefully acknowledged.

REFERENCES

[1] A. Ananta, A New Classification of Indonesia's Ethnic Groups, the Institute of Southeast Asian Studies, Singapore, 2014.

[2] P. v. d. Logt, Climate Change Profile: Indonesia, Netherlands Commission for Environmental Assessment, 2016.

[3] H. Wang, Decay Above-Ground, CSIRO Sustainable Ecosystem, Victoria, 2008.

[4] R.A. Zabel, and J.J. Morrell, Wood microbiology: Decay and its prevention. ISBN: 0-12-775210-2 Academic Press, Inc. San Diego, California, 1992.

[5] Badan Pusat Statistik, Provinsi Kalimantan Barat dalam Angka 2016, Pontianak, Kalimantan Barat, 2016.

[6] The Wood Construction Section of Committee for Normalizing, Regulation of Indonesian timber construction 1961, Directorate of Investigation of Building Problems, Bandung, 1976 (in Bahasa).

[7] S. Prajadinata, Review of Management and Conservation Status of Ulin Ebony and Cempaka in Indonesia, Forestry Research and Development Agency, Ministry of Forestry, 2011.

[8] A. Martawijaya, Indonesian Wood Atlas, Forestry Research and Development Agency, Ministry of Forestry, Bogor, 2005 (in Bahasa).

[9] C.H. Wang, Timber service life design: Design guide for durability, Forest and Wood Products Australia, 2012.

[10] ASTM. ASTM F2170 - 16b Standard Test Method for Determining Relative Humidity Using in situ Probes International A, editor. West Conshohocken, PA: ASTM; 2016.