Identifying Viable Preservation Methods for Rust Corrosion and Fungi Deterioration in Wood and Concrete Structure and Developing a Monitoring System for the Conservation of the Mrigadayavan Palace

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Abstract

Currently, the problems of rust corrosion and growth of fungi resulting in the deterioration of wood and concrete structures of the Mrigadayavan Palace are becoming more serious. These problems are considered to be a major roadblock in restoring the palace back to its original beauty. Therefore, the ultimate goal of this project is to help preserve the original structure of the Mrigadayavan Palace as per request of the Mrigadayavan Palace Foundation staff to complete the restoration project by 2024 for the Palace's 100th anniversary. By analyzing the information obtained from observation, research and studies, and conversation with palace staff and experts, we gained more understanding and insight on the causes of these problems and methods to prevent them. We also suggested some recommendations on preservation and prevention methods as well as ways to monitor the efficiency of the recommended methods.

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Executive Summary

Introduction

Mrigadayavan Palace, a seaside residence for His Majesty King Vajiravudh, or King Rama VI, who ruled Siam from 1910 to 1925, is a historical site in Thailand that combines art, history, nature, and architecture together. The palace was built with influences from both Thai and Western designs, combining wood and concrete constructions together. The palace was constructed mainly with teak wood in the main structures and walkways, and concrete for its foundation and support columns. Over time, the value of the palace in terms of history, art, and architecture had slowly declined. Therefore, the Mrigadayavan Palace Foundation is currently working on a restoration project to restore the palace to a state comparable to when it was first built. The project includes an aim to preserve the structure of wood and concrete of the Mrigadayavan Palace from the destructive effect of rust and fungi, considering both authenticity and aesthetic beauty. The Foundation aims to complete this restoration project by 2024, in time for the Palace's 100th anniversary.

Problems

Recently, the palace staff has been noticing an increase in occurrence of rust forming around the head of nails in wooden structures, the growth of fungi on wood, and the cracking and spalling of columns that contain internal reinforcing bars that have started to rust. The staff has been trying different methods to prevent rust and fungi and preserve wood, but many of those methods used have not been effective. Additionally, after these methods have been applied, they have not been monitored, and new occurrences of rust and fungi have been reported by staff who stumble upon these areas and notice them. This problem is further complicated due to the presence of different materials in the structure, namely wood, iron nails, and concrete. Chemicals contained in products that are applied may have beneficial effects to one material, but may be detrimental to another. Thus, there should be careful selection of the preservative products or methods to be used and applied.

Goals

The goals of this project are to understand the deterioration of wood and concrete structure caused by the corrosion of nails and reinforcing bars, understand how fungi grow in wood, identify methods to prevent rust and fungi, and design a monitoring program to monitor the effects of different solutions applied. All of these goals lead to the ultimate goal of preserving the original structure of the Mrigadayavan Palace in order to serve as both a natural and cultural museum.

Methodology and Objectives

The team has set four objectives in order to achieve these goals:

1. **Assessing the Extent of Corrosion**
   The team started by performing empirical research by visiting the palace to study the impact of the problem and observing different locations of the palace where corrosion and fungal growth occurs. In addition, with the extra information gained from palace staff and experts, the current condition of the palace was better understood.
2. **Understanding and Identifying the Most Suitable Methods of Corrosion Prevention, Fungi Removal and Prevention, and Wood Preservation**
   The team performed background research and looked through studies on preservative methods tested in many papers published by scientists in order to understand the formation of rust and fungi in order to better understand the effectiveness or mechanisms of different methods. Additionally, we also considered the complications that arise when these methods are used together and on different materials as well as the principles of conservation of authenticity and aesthetics. Along with the research performed, our team also interviewed experts in different fields, including scientific, historical, and social aspects to gain more understanding and information on preservative methods. All the methods found were then combined and compared and a chart of preservative methods with the most potential and their effects on different materials were suggested to the staff.
3. **Initiating a Monitoring Program**
   As per request of the staff, a monitoring program that is easy to perform by non-scientist staff and cost-effective would help with preservation and keeping information organized. More literature review was done on how rust and fungi in wood is monitored in different historical buildings in other countries. From the

insight gained from other research, the team designed a simple monitoring system through the uses of a series of charts and tables along with guides and manuals in order for the staff to keep record and track the data.

4. **Presenting Information for the Benefit of the Palace and the Public**
   We summarized the knowledge obtained from different research and studies explaining the causes of nail corrosion in teak wood, methods for rust prevention, suitable wood preservatives, and the set-up of a monitoring system for corrosion and presented the information to the staff for their opinion to further develop the information to be available for visitors to the palace. The information was then designed in the form of infographics to make the information more interesting and attractive to viewers. Our team also designed a way to implement the infographics onto the actual structures of the palace by turning the infographics into QR codes.

Findings and Analysis

1. **Different areas of the palace are affected at varying levels of severity depending on the proximity to the ocean.**
   After analyzing the levels of severity of the problems of rust and fungi and mapping out the locations of those spots around the palace, we found that the palace structures closer to the ocean were affected by rust and fungi more severely than structures found inland.
2. **The problem of rust stems from the carelessness and lack of thorough understanding of the consequences of previously used restorative methods.**
   The team analyzed the information gained by comparing the structures after previous restorations to the original structures before restoration. The result shows that the restoration methods previously used seem to be incorrect and ineffective because rust was not present or noticeable in the original wooden and concrete structures, however after previous restoration was performed, the growth of rust was more noticeable and evident.
3. **Fungi is a recurring problem due to the lack of interest in making sure the wood has completely dried before applying wood products.**
   According to research and interviews with experts, wood should be dried thoroughly in order to avoid fungal growth on the wood. However, the presence of tall trees near wooden structures and puddles of water observed on the wooden floor around the palace

contributed to increased moisture in wood. Currently, wet wood is only left to air dry, which may dry the surface of the wood, but moisture is still contained inside the wood, and leftover moisture could lead to the growth of fungi once again.

4. **Not all methods that were researched were viable or compatible with all materials.** Through review of research papers and scientific studies, many methods for preserving wood and preventing rust and fungi were found, but not all chemicals were suitable for use with all materials in the palace structure. A table was compiled to compare the cost, toxicity, and environmental effects to determine suitable recommendations for the staff.
5. **The palace does not have an organized or systematic monitoring program.** After discussions with the palace staff, there is currently no organized or systematic way to check for the growth of rust and fungi or to monitor the effectiveness of products used.
6. **The palace does not have an exhibition dealing with scientific and restorative aspects.** Through meetings and discussions with the palace staff, the current exhibition in the palace contains only historical and cultural information. They are planning to expand into more diverse fields including scientific aspects, and the information gathered by the team could be of great help in expanding the knowledge base contained in the exhibition.

Recommendations

To deal with rust on iron nails, the team recommends removing the rust first and coating the nails with substances that prevent rust or a complete replacement with stainless steel nails. Alternatively, tannic acid can be directly applied on rust to prevent the metal underneath from further rusting. This method does not require cleaning or removing rust as tannic acid can convert rust surface into a protective layer, to help protect the nails and prolong rust in areas that are waiting to be repaired.

To repair cracked concrete columns with rusted internal rebars, the team recommends replacing the internal rebars with epoxy-coated rebars to extend lifespan of the rebars. Fly ash or polymers can be added to the cement mix to form concrete that is less penetrative to gases and moisture, which are the causes of rust and corrosion. Additionally, the team recommends that the thickness of concrete covering the rebars should be at least 3 inches.

To remove fungi, products containing hypochlorite, such as bleach, or Dettol should be used. Afterwards, the wood should be kiln-dried in an oven to make sure that the inside of the wood is truly dry. Wood preservatives that the team recommends are copper chrome boron (CCB) for furniture and indoor use and micronized copper azole (MCA) for outdoor use to prevent fungal growth on the wood.

Afterward, wood finishes can finally be applied. Teak oil is applied to keep the wood saturated with oil and prevent moisture from entering into the wood, and teak sealer or wax can be applied on top to prevent the applied oil from drying out. Alternatively, deck stain can be used instead, since the stain itself contains oil, and also gives the wood a more natural look.

Finally, the team recommends that the staff monitors the products that they apply at regular intervals because the life span of different products can vary depending on the location where they are used.

บทสรุปสำหรับผู้บริหาร

บทนำ

พระราชนิเวศน์มฤคทายวันเป็นที่ประทับแปรพระราชฐานริมทะเลของพระบาทสมเด็จพระปรเมนทรมหาวชิราวุธ หรือพระบาทสมเด็จพระมงกุฎเกล้าเจ้าอยู่หัว (รัชกาลที่ ๖) ซึ่งเป็นผู้ปกครองสยามตั้งแต่ปี พ.ศ. ๒๔๕๓ จนถึง พ.ศ. ๒๔๖๘ พระราชนิเวศน์มฤคทายวันแห่งนี้ ถือเป็นสถานที่ที่มีความสำคัญทางประวัติศาสตร์เป็นอย่างมาก โดยมีการนำศิลปะ ธรรมชาติ และสถาปัตยกรรมมาผสมผสานเข้าไว้ด้วยกัน พระราชนิเวศน์แห่งนี้สร้างขึ้นโดยได้รับอิทธิพลทั้งจากศิลปะของไทยและศิลปะทางตะวันตก ซึ่งมีรูปแบบการสร้างเป็นการผสมผสานทั้งไม้และปูนไว้ในตัวอาคาร โดยที่ไม้สักจะอยู่บริเวณโครงสร้างหลักและทางเดินของตัวพระราชนิเวศน์ ส่วนปูนนั้นเป็นฐานราก และเสาค้ำสำหรับช่วยในการรับน้ำหนักของตัวอาคาร เมื่อเวลาผ่านไป คุณค่าทางประวัติศาสตร์ ศิลปะ และสถาปัตยกรรมได้ลดลงเนื่องจากการเสื่อมสภาพของพระราชนิเวศน์ตามกาลเวลา ดังนั้นทางมูลนิธิพระราชนิเวศน์มฤคทายวัน ในพระอุปถัมภ์ฯ จึงมีการดำเนินการจัดทำโครงการการบูรณะพระราชนิเวศน์ขึ้น เพื่อเป็นการฟื้นฟูและคืนสภาพพระราชนิเวศน์ให้กลับมามีสภาพเทียบเท่ากับสมัยที่สร้างพระราชนิเวศน์เป็นครั้งแรก โครงการบูรณะนี้มีจุดมุ่งหมายเพื่อรักษาโครงสร้างของไม้และคอนกรีตในพระราชวัง ซึ่งเกิดจากการทำลายของสนิมและเชื้อรา โดยจะคำนึงถึงความดั้งเดิมและความสวยงามของพระราชนิเวศน์ มูลนิธิพระราชนิเวศน์มฤคทายวันมุ่งหมายที่จะดำเนินการโครงการบูรณะนี้ ให้เสร็จสิ้นภายในปี พ.ศ. ๒๕๖๗ ซึ่งจะเป็นปีที่พระราชนิเวศน์ครบรอบ ๑๐๐ ปี

ปัญหา

ณ ปัจจุบัน เจ้าหน้าที่ของทางมูลนิธิพระราชนิเวศน์ได้มีการสำรวจและสังเกตเห็นการก่อตัวที่เพิ่มขึ้นของสนิมที่อยู่บริเวณโดยรอบหัวตะปูในโครงสร้างของไม้ รวมถึงได้มีการสังเกตเห็นการเจริญเติบโตของเชื้อราในไม้และการแตกและหลุดร่อนของคอนกรีตบนเสาปูนที่มีเหล็กเสริมอยู่ด้านใน ซึ่งคาดว่าน่าจะเกิดจากการก่อตัวของสนิมบนเหล็กเส้นภายใน เจ้าหน้าที่ได้มีการลองใช้วิธีต่าง ๆ เพื่อป้องกันการเกิดสนิม เชื้อรา และรักษาเนื้อไม้ แต่หลาย ๆ วิธีที่ได้มีการลองใช้นั้นไม่ได้ผล และนอกจากนี้ วิธีที่ได้มีการทดลองใช้ ยังไม่มีการสังเกตการณ์ การตรวจสอบ หรือบันทึกอย่างถูกต้อง การเกิดขึ้นใหม่ของสนิมและเชื้อราส่วนมากจะถูกรายงานโดยเจ้าหน้าที่ของมูลนิธิที่ผ่านและสังเกตเห็นปัญหาในบริเวณนั้น ๆ ยิ่งไปกว่านั้น ปัญหานี้มีความซับซ้อนเนื่องจากตัวพระราชนิเวศน์ถูกสร้างขึ้นด้วยวัสดุหลากหลายชนิด เช่น ไม้ ตะปูเหล็ก และคอนกรีต สารเคมีที่อยู่ในผลิตภัณฑ์ต่าง ๆ อาจมีผลดีต่อ

วัสดุชนิดนึง แต่อาจะเป็นอันตรายหรือทำลายวัสดุอีกชนิดหนึ่ง ดังนั้นการเลือกวิธีที่จะจัดการปัญหาต่าง ๆ ในโครงสร้างของพระราชนิเวศน์มีความสำคัญมาก จึงควรระมัดระวังและไตร่ตรองวิธีที่จะจัดการปัญหาให้รอบด้าน

เป้าหมาย

โครงงานนี้มีเป้าหมายในการเข้าใจกระบวนการผุของไม้และการเสื่อมสภาพของคอนกรีตที่เกิดขึ้นจากการกัดกร่อนของสนิมและเหล็กเสริม เข้าใจการเติบโตของเชื้อราในไม้ หาวิธีการป้องกันการเกิดสนิมและเชื้อรา และการวางแบบแผนในการสังเกตการณ์ผลของการใช้วิธีป้องกันและรักษาต่าง ๆ เป้าหมายทั้งหมดมีจุดมุ่งหมายสูงสุดในการอนุรักษ์โครงสร้างของพระราชนิเวศน์มฤคทายวันเพื่อสามารถใช้ตัวพระราชนิเวศน์เป็นพิพิธภัณฑ์ที่มีชีวิตที่แสดงถึงวัฒนธรรมและธรรมชาติในสถานที่แห่งนี้

ระเบียบวิธีและวัตถุประสงค์

คณะผู้วิจัยได้ตั้งวัตถุประสงค์ ๔ ข้อเพื่อให้บรรลุเป้าหมายที่ตั้งไว้ดังนี้

๑. การประเมินความเสียหายของโครงสร้างที่เกิดจากการกัดกร่อน

คณะผู้วิจัยได้เริ่มต้นจากการทำการวิจัยเชิงประจักษ์ ซึ่งเป็นการทำการวิจัยจากข้อมูลปฐมภูมิ โดยมีการลงพื้นที่ไปทำการสำรวจพระราชนิเวศน์ เพื่อศึกษาผลกระทบและปัญหาที่เกิดขึ้นในบริเวณพระราชนิเวศน์ รวมถึงทำการสังเกตดูจุดต่าง ๆ ในพระราชนิเวศน์ที่เกิดการกัดกร่อนของสนิม และการเจริญเติบโตของเชื้อรา นอกจากนี้คณะผู้วัจัยยังได้รับข้อมูลเพิ่มเติมจากเจ้าหน้าที่ของมูลนิธิพระราชนิเวศน์ ทำให้เข้าใจสถานการณ์และสภาพปัจจุบันของพระราชนิเวศน์ได้ดียิ่งขึ้น

๒. การทำความเข้าใจและหาวิธีป้องกันที่เหมาะสมที่สุด ต่อการกัดกร่อนของสนิม และการกำจัดสนิมและเชื้อรา รวมถึงการดูแลรักษาเนื้อไม้

คณะผู้วิจัยได้ทำการวิจัยและศึกษาความเป็นมาและความสำคัญของปัญหาที่เกิดขึ้น รวมถึงศึกษาเกี่ยวกับวิธีการป้องกันปัญหา โดยพิจารณาและวิเคราะห์จากเอกสารการค้นคว้า วิจัย และทำการทดลองที่ถูกตีพิมพ์โดยนักวิทยาศาสตร์ เพื่อให้เข้าใจถึงปัญหาการเกิดสนิมและเชื้อรา เข้าใจประสิทธิภาพและกลไกการทำงานของวิธีป้องกันต่าง ๆ ได้ดียิ่งขึ้น นอกจากนี้ คณะผู้วิจัยยังได้พิจารณาถึงความซับซ้อนที่อาจเกิดขึ้นเมื่อนำวิธีต่าง ๆ มาใช้ร่วมกันกับวัสดุที่แตกต่างกัน ตลอดจนคำนึงถึงหลักการอนุรักษ์ที่ต้องคงไว้ทั้งความดั้งเดิมของโครงสร้างและความสวยงาม นอกเหนือจากการวิจัยโดยค้นคว้าหาข้อมูลทุติยภูมิแล้ว คณะผู้วิจัยยังได้มีการสัมภาษณ์ผู้เชี่ยวชาญที่มีความรู้ในด้านต่าง ๆ เช่น วิทยาศาสตร์ ประวัติศาสตร์

หรือสังคม เพื่อให้เข้าใจปัญหาและแง่มุมต่าง ๆ มากขึ้น จากนั้นคณะผู้วิจัยได้ทำการรวบรวมข้อมูล วิธีการป้องกัน และอนุรักษ์ต่าง ๆ ไว้ด้วยกัน และทำการเปรียบเทียบในรูปแบบของตาราง เพื่อให้ทางเจ้าหน้าที่ของมูลนิธิพระราชนิเวศน์หรือผู้ที่จะนำข้อมูลเหล่านี้ไปใช้ เห็นถึงการเปรียบเทียบและผลกระทบของวิธีต่าง ๆ ต่อวัสดุชนิดต่าง ๆ ที่ชัดเจนมากยิ่งขึ้น

๓. การริเริ่มแผนงานในการประเมินและติดตามความเสียหาย

จากข้อมูลที่ได้รับจากเจ้าหน้าที่ของพระราชนิเวศน์ แผนงานในการประเมินต้องง่ายต่อการใช้งาน ผู้ที่ไม่มีความรู้เกี่ยวกับงานทางด้านวิทยาศาตร์จะต้องสามารถใช้ได้ รวมถึงต้องมีค่าใช้จ่ายที่ประหยัดในการใช้งาน ทางคณะผู้วิจัยได้ทำหาข้อมูลเพิ่มเติม และทำการทบทวนวรรณกรรมเกี่ยวกับวิธีการสังเกตุ ประเมิน และจดบันทึกความเสียหายที่เกิดขึ้นจากสนิมและเชื้อราในไม้ ในโครงสร้างต่าง ๆ คณะผู้วิจัยได้ทำการค้นหาข้อมูลจากวิธีการประเมินและเก็บข้อมูลของโบราณสถานต่าง ๆ ในหลายประเทศ จากข้อมูลที่ได้ค้นคว้ามาคณะผู้วิจัยจึงได้ทำการออกแบบและริเริ่มแผนงานในการประเมินความเสียหายในรูปแบบของเอกสารและตาราง พร้อมทั้งให้ข้อมูลในการใช้ตารางการประเมินในรูปแบบของคู่มือและคำแนะนำในการใช้ เพื่อให้เจ้าหน้าที่หรือผู้ที่จะนำตารางไปใช้ สามารถบันทึกและติดตามข้อมูลได้โดยง่าย

๔. การสรุปข้อมูลเพื่อให้เกิดประโยชน์แก่พระราชนิเวศน์และผู้เข้าชม

คณะผู้วิจัยได้ทำการรวบรวมและสรุปองค์ความรู้ที่ได้ทั้งหมดจากการค้นคว้า วิจัย ที่อธิบายถึงสาเหตุของการเกิดการกัดกร่อน การกำจัดและป้องกันสนิมและเชื้อรา รวมถึงการออกแบบระบบการตรวจสอบและประเมินความเสียหาย และได้ทำการเสนอข้อมูลเหล่านี้ไปยังเจ้าหน้าที่ของพระราชนิเวศน์ เพื่อเป็นการเตรียมพร้อมและพัฒนาข้อมูลให้เกิดประโยชน์สูงสุดแก่ผู้ที่มาเยี่ยมชมพระราชนิเวศน์ต่อไปในอนาคต จากนั้นข้อมูลที่ถูกรวบรวมจะถูกนำไปออกแบบให้อยู่ในรูปแบบของอินโฟกราฟิก เพื่อทำให้ข้อมูลมีความน่าสนใจ และดึงดูดผู้เยี่ยมชมมากขึ้น คณะผู้วิจัยยังได้ทำการออกแบบคิวอาร์โค้ดเพิ่มเติม เป็นการนำอินโฟกราฟิกรวบรวมไว้อยู่ในคิวอาร์โค้ด เพื่อให้ทางเจ้าหน้าที่นำไปใช้ในสถานที่แต่ละจุดในพระราชนิเวศน์ได้

ผลและการวิเคราะห์ผล

๑. บริเวณต่าง ๆ ในพระราชนิเวศน์ได้รับผลกระทบในระดับความรุนแรงที่แตกต่างกันไป ขึ้นอยู่กับความใกล้ชิดกับทะเล

หลังจากที่ได้ทำการวิเคราะห์และประเมินระดับความรุนแรงของการเกิดขึ้นของสนิมและเชื้อรารวมถึงการวาดแผนผังชี้ผลกระทบและความรุนแรงของปัญหาในแต่ละจุดบริเวณรอบพระราชนิเวศน์ที่เกิดขึ้นแล้ว คณะผู้วิจัยได้พบว่าโครงสร้างของพระราชนิเวศน์ที่อยู่บริเวณใกล้ริมทะเลได้รับผลกระทบจากการก่อตัวของสนิมและการเจริญเติบโตของเชื้อรามากกว่าโครงสร้างที่อยู่บริเวณด้านในซึ่งห่างจากทะเล

๒. ปัญหาสนิมเกิดขึ้นจากความประมาท ไม่รอบคอบ และขาดความเข้าใจอย่างถ่องแท้ต่อปัญหาและผลที่ตามมาของวิธีการบูรณะรักษาโครงสร้างที่เคยใช้ก่อนหน้านี้

คณะผู้วิจัยได้รวบรวมและวิเคราะห์ข้อมูลต่าง ๆ ที่ได้มา โดยทำการเปรียบเทียบระหว่างโครงสร้างหลังจากทำการบูรณะแล้วกับโครงสร้างครั้งเมื่อพระราชนิเวศน์ถูกสร้างขึ้นก่อนทำการบูรณะ ผลปรากฏให้เห็นว่าการบูรณะอาจทำในวิธีที่ไม่ถูกต้อง และไม่เกิดประสิทธิภาพที่ดี เพราะการก่อตัวของสนิมไม่ปรากฏให้เห็นในโครงสร้างแรกเริ่มของพระราชนิเวศน์ ทั้งบนไม้และคอนกรีต แต่กลับเกิดปัญหาให้เห็นชัดเจนมากขึ้นหลังจากทำการบูรณะซ่อมแซมแล้ว

๓. เชื้อราเป็นปัญหาที่เกิดขึ้นซ้ำ ๆ เนื่องจากความไม่สนใจและการละเลยในการดูแล รวมถึงไม่มีการตรวจสอบให้แน่ชัดว่าไม้แห้งสนิทก่อนที่จะลงผลิตภัณฑ์ดูแลรักษาเนื้อไม้ชนิดต่าง ๆ

จากการที่ได้ทำการวิจัย รวบรวมข้อมูล และสัมภาษณ์ผู้เชี่ยวชาญ พบว่าไม้ควรจะนำมาทำให้แห้งเพื่อป้องกันการเจริญเติบโตและการกลับมาของเชื้อราในเนื้อไม้ อย่างไรก็ตามต้นไม้ที่อยู่บริเวณรอบ ๆ โครงสร้างอาคาร รวมถึงแอ่งน้ำที่ขังอยู่บนแผ่นไม้ซึ่งปรากฏให้เห็นอยู่บริเวณพื้นไม้ของพระราชนิเวศน์ เป็นปัจจัยที่มีส่วนในการเพิ่มความชื้นให้กับโครงสร้างไม้ของพระราชนิเวศน์ ซึ่งทำให้การดูแลเป็นไปได้ยากมากยิ่งขึ้น ณ ปัจจุบัน แผ่นไม้ที่ชื้นถูกปล่อยให้แห้งโดยการตากลมตากอากาศปกติ ไม่ได้มีวิธีเฉพาะในการดูแลทำให้ไม้แห้ง ซึ่งวิธีนี้จะทำให้ไม้แห้งแค่บริเวณพื้นผิวเท่านั้น แต่ความชื้นที่ขังอยู่ภายในยังคงอยู่ในตัวเนื้อไม้ และความชื้นนี้สามารถส่งผลต่อการเจริญเติบโตและกลับมาของเชื้อราต่อไปได้

๔. วิธีทั้งหมดที่ได้ทำการค้นคว้าวิจัยมา ไม่สามารถใช้งานร่วมกันเอง หรือกับวัสดุชนิดต่าง ๆ ได้หมดทุกวิธี

จากการค้นคว้า ศึกษา และหาข้อมูลทางวิทยาศาสตร์ มีหลากหลายวิธีที่สามารถใช้รักษา ดูแลเนื้อไม้และป้องกันสนิมและเชื้อราได้ แต่วิธีต่าง ๆ ที่สืบค้นมาได้นั้น ไม่สามารถใช้ร่วมกันได้ และไม่ใช่ทุกวิธีที่จะเหมาะสมกับวัสดุที่ใช้ใน

โครงสร้างของพระราชนิเวศน์ ดังนั้นทางคณะผู้วิจัยได้สร้างตารางที่รวบรวมวิธีเหล่านี้ขึ้นมาเพื่อเปรียบเทียบประสิทธิภาพในการใช้งาน รวมถึงค่าใช้จ่าย ความเป็นพิษหรือระดับความอันตราย และผลกระทบที่อาจเกิดขึ้นต่อสิ่งแวดล้อม เพื่อเป็นส่วนช่วยในการเลือกวิธีที่เหมาะสมที่สุดในการนำมาใช้กับพระราชนิเวศน์

๕. พระราชนิเวศน์ไม่มีระบบการดูแลและติดตาม

หลังจากที่ได้ทำการพูดคุยและปรึกษากับเจ้าหน้าที่ของพระราชนิเวศน์ พบว่าปัจจุบันนี้ทางพระราชนิเวศน์ยังไม่มีระบบหรือแบบแผนในการดูแลติดตามปัญหาของสนิมและการเจริญเติบโตของเชื้อราอย่างเป็นระบบ รวมถึงไม่มีการติดตามและบันทึกถึงประสิทธิภาพของผลิตภัณฑ์ที่ใช้ในการดูแลโครงสร้างอาคารของพระราชนิเวศน์

๖. พระราชนิเวศน์ไม่มีนิทรรศการที่ให้ข้อมูลเกี่ยวกับความรู้ และมุมมองทางด้านวิทยาศาสตร์ต่อปัญหาที่เกิดขึ้น

จากการพูดคุยและสอบถามข้อมูลจากเจ้าหน้าที่ของพระราชนิเวศน์ พบว่าปัจจุบันทางพระราชนิเวศน์มีการจัดนิทรรศการที่ให้ข้อมูลแค่ทางด้านประวัติศาสตร์ และด้านศิลปะวัฒนธรรมเท่านั้น แต่ขณะนี้ทางพระราชนิเวศน์กำลังพิจารณาถึงการดำเนินการขยายนิทรรศการเพื่อเป้าหมายในการให้ความรู้ที่ครอบคลุมในหลากหลายด้านมากขึ้น เช่น ในด้านของข้อมูลทางวิทยาศาสตร์ และข้อมูลที่ทางคณะผู้วิจัยได้ค้นคว้าหามานั้น อาจมีส่วนช่วยในการขยายนิทรรศการเพื่อให้ความรู้ต่อผู้เยี่ยมชมต่อไปในอนาคตได้

ข้อเสนอแนะ

เพื่อเป็นการจัดการกับปัญหาสนิมบนตะปูเหล็ก ทางคณะผู้วิจัยเสนอให้มีการกำจัดสนิมออกจากตะปูก่อน และทำการเคลือบตะปูด้วยสารที่สามารถป้องกันสนิมได้ หรือทำการเปลี่ยนตะปูด้วยตะปูสแตนเลสใหม่ทั้งหมด อีกวิธีหนึ่งก็คือการใช้กรดแทนนิกทาลงบนพื้นผิวสนิมโดยตรง โดยวิธีนี้จะไม่ต้องทำการกำจัดหรือทำความสะอาดสนิมออกก่อน เพราะกรดแทนนิกจะมีฤทธิ์สามารถเปลี่ยนพื้นผิวสนิมให้กลายเป็นพื้นผิวที่ปกป้องตะปูเหล็กข้างใต้ ช่วยป้องกันและยืดอายุการใช้งานของตะปูเหล็กได้

ในการซ่อมแซมเสาคอนกรีตที่แตกร้าวจากการเกิดสนิมและกัดกร่อนจากเหล็กเส้นภายใน ทางคณะผู้วิจัยขอเสนอให้ทำการเปลี่ยนเหล็กเส้นภายในเป็นเหล็กเส้นเคลือบอีพ็อกซี หรือเหล็กเส้นสีเขียว เพราะจะมีอายุการใช้งานที่นานกว่าเหล็กเส้นทั่วไปที่ไม่มีสารเคลือบ การผสมเถ้าลอยหรือโพลิเมอร์ลงไปในส่วนผสมปูนซีเมนต์ก็เป็นอีกวิธีหนึ่งที่สามารถช่วยป้องกันการเกิดสนิมของเหล็กเส้นภายในได้ เนื่องจากเป็นการช่วยลดการซึมผ่านของแก๊สและความชื้น ที่เป็นสาเหตุการเกิดสนิม ความหนาของเสาคอนกรีตที่หุ้มเหล็กเส้น ทางคณะผู้วิจัยแนะนำควรให้มีความหนาอย่างน้อย ๓ นิ้ว

ในการกำจัดเชื้อรา ควรใช้เดทตอลหรือผลิตภัณฑ์ที่มีส่วนผสมของไฮโปคลอไรท์ เช่นไฮเตอร์ ในการกำจัด หลังจากกำจัดเชื้อราแล้ว ควรทำให้ไม้แห้งโดยการอบไม้เพื่อให้มั่นใจว่าเนื้อไม้ข้างในนั้นแห้งสนิทแล้ว น้ำยารักษาเนื้อไม้เพื่อป้องกันการเกิดเชื้อราที่คณะผู้วิจัยแนะนำคือคอปเปอร์โครมโบรอน (ซีซีบี) และ ไมโครไนซ์คอปเปอร์เอโซล (เอ็มซีเอ) ซีซีบีสามารถใช้รักษาเฟอร์นิเจอร์และไม้ที่อยู่ภายในตัวอาคาร เอ็มซีเอสามารถใช้รักษาไม้ที่ใช้ภายนอกได้

หลังจากนั้นทางคณะวิจัยแนะนำให้ลงน้ำมันรักษาเนื้อไม้หรือทีคออยล์เพื่อให้เนื้อไม้อุ้มน้ำมันเพื่อกันความชื้นไม่ให้เข้าไปในเนื้อไม้ หลังจากนั้นให้ใช้ทีคซีเลอร์หรือแว็กซ์เพื่อกันไม่ให้น้ำมันในเนื้อไม้ระเหยออกมา อีกทางเลือกหนึ่งคือการใช้สีย้อมพื้นไม้หรือเดคสเตนเพราะในสีย้อมพื้นไม้นั้นมีส่วนผสมของน้ำมันอยู่และสามารถทำให้ไม้มีลักษณะความเป็นธรรมชาติมากขึ้น

สุดท้ายนี้ทางคณะผู้วิจัยแนะนำให้เจ้าหน้าที่ของมูลนิธิดูแลและติดตามผลกระทบของผลิตภัณฑ์ที่ใช้เป็นระยะ ๆ เพราะอายุการใช้งานของผลิตภัณฑ์ต่าง ๆ อาจแตกต่างตามสภาพแวดล้อมที่ใช้งาน

Authorship Page

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Chapter 1 - Introduction

The Mrigadayavan Palace is a summer palace built in 1924 for His Majesty King Vajiravudh, or King Rama VI, and is situated by the seaside in Cha-am district of Petchaburi. After the passing of King Rama VI, the palace had fallen into disuse until 1965 when the Border Patrol Police were allowed to use the palace as training grounds. The palace was registered as a heritage site in 1981 by the Fine Arts Department, and in 1992, the Mrigadayavan Palace Foundation was established under royal patronage to oversee the conservation of the palace. The Foundation's vision is to restore the palace to its original state by 2024 for its 100th anniversary. However, the problems of rust and fungi, which cause deterioration in wood, as well as the deterioration of concrete by the corrosion of internal reinforcing bars have been a major roadblock in restoring the palace to its original beauty.

The palace was constructed from a combination of two main building materials: teak wood for its main structures and walkways, and concrete for its foundation and support columns. The hybrid construction system of wood and concrete was first introduced to Thailand during the reign of King Rama IV (Satittawilwong, 2012). Due to increased interaction with the western world, Thai architecture started to be influenced by western ideas, causing buildings to look more western, but still containing some elements of Thai culture, such as in Thai traditional houses. The ground floor of these houses were constructed with concrete, and the upper level was constructed with wood, representing the integration between Thai and western style, which is similar to the structure of Mrigadayavan Palace. The combination between wood and concrete construction results in a challenging task for the conservation of the palace's structure due to different effects of preservatives on the different materials.

Nail corrosion and growth of fungi in wood, as well as the deterioration of concrete structure, are common problems in mixed concrete-wood infrastructures after long-term exposure to coastal conditions, such as increased humidity and sea salt spray from the ocean. The palace structure is constructed with golden teak, and the weakening of wood is frequently observed around the iron nails, which could cause a weakening of the palace structure if the corrosion is left to progress. Methods of prevention would greatly benefit the palace, and the information gained can also be distributed for the public for those who also encounter this problem in their own homes near the ocean.

The palace staff have been exploring different methods to preserve the structure of the palace, but many have not worked, therefore the staff would like to understand the causes of rust and fungal growth and find more suitable ways to prevent them. Rust and fungi have deteriorated some of the wooden planks, and rust has also affected the internal rebars of concrete columns, which now exceedingly affects the majority of the wooden and concrete structure of the palace. Thus, the staff have tried different treatments to preserve the wood and prolong deterioration, such as using urethane coating on wood or the application of teak oil and wax. However, these treatments have been unsuccessful, such as in the incomplete application of wax, or even potentially harmful, such as in the coating of urethane, which is not suitable for long term use.

According to the problems stated above, the structure of the palace has been affected by rust and fungi, and this problem is now becoming more severe, requiring more effective solutions. If the causes of corrosion and prevention methods are not found, the structural integrity of the palace will continue to weaken, resulting in the palace having to replace all of the damaged wooden structures, which can be costly. Therefore, in order to be able to understand the problem thoroughly and be able to effectively find solutions, research and study on the previous restoration processes, compositions of nails, rust, wood, and concrete, and different species of fungi need to be explored. From last year's ISSP team that worked with the Mrigadayavan Palace Foundation to assess the impact of human activity on groundwater, they discovered that the groundwater was starting to increase in salinity (Cohn et al., 2020). This increase in salinity is worrying because the growth of rust can be accelerated by salt in the air. Therefore, appropriate ways to prevent and remove rust and fungi effectively should also be explored.

This project aims to preserve the structure of wood and concrete of the Mrigadayavan Palace from the destructive effect of rust and fungi because the current condition of the palace structure is heavily deteriorated. Due to the humidity and catalysts such as sea salt in the environment of the palace, the wooden structure of the palace tends to deteriorate at an increasing rate. In order to be able to achieve the main goal of this project, we set the following objectives: assessing the extent of the corrosion in the palace buildings, understanding and identifying the most suitable methods of corrosion prevention and wood preservation, designing a monitoring program for the palace staff to keep track of corrosion in the palace, and summarizing, presenting, and suggesting our findings to the palace staff to be distributed to any interested visitors.

Chapter 2 - Literature Review

2.1 - Mrigadayavan Palace and Foundation

2.1.1 - History of the Mrigadayavan Palace

Mrigadayavan Palace, a seaside residence for His Majesty King Vajiravudh, or King Rama VI, who ruled Siam from 1910 to 1925, is a historical site in Thailand that combines art, history, nature, and architecture together. The original purpose of the palace was to serve as a place with a warm and airy climate for the King to reside as recommended by his personal physician due to the King's rheumatoid arthritis. The King also wanted the palace to look simple and designed to suit the geography and climate.

In 1981, after a long period of disuse, the palace was registered as a heritage site by the Fine Arts Department. A decade later in 1992, the Mrigadayavan Palace Foundation was established under the patronage of Her Royal Highness Princess Bejaratana, the only daughter of King Rama VI. HRH Princess Bejaratana hoped that the palace could serve as a learning center for the population to learn about and show gratitude towards the reign of King Rama VI. Since then, the Mrigadayavan Palace has been under the management of the Mrigadayavan Palace Foundation.

2.1.2 - Architecture and Structure of the Mrigadayavan Palace

King Rama VI intended Mrigadayavan Palace to be a humble seaside palace in order to minimize construction expenses. The King designed initial sketches, and Ercole Pietro Manfredi, an Italian architect, implemented his designs and oversaw the palace's construction from 1923 until late 1924. The palace was built with influence from both Thai and Western designs.

The palace itself consists of 16 teak buildings and 23 staircases that are connected by balconies and corridors and divided into three main sections: Samosorn Sevakamart throne hall (พระที่นั่งสโมสรเสวกามาตย์), Samutpiman quarters (หมู่พระที่นั่งสมุทรพิมาน), and Pisansakorn quarters (หมู่พระที่นั่งพิศาลสาคร). The roof of the palace is covered by rhombus tiles, which help to keep out sunlight and rain. Underneath the buildings, which are elevated by columns, is a concrete floor. The buildings are designed with high ceilings and many windows, which provides good airflow and ventilation, resulting in a well-ventilated and less humid atmosphere. Even though this is a huge palace, the King had an order to finish building the palace within a year, therefore some of the structures made from teak wood were made in Bangkok and sent to the construction site, while other parts of the palace were made from concrete. However, there is no connecting material between the wood and concrete columns, except for the structures near the beach where the concrete and wood are connected by metal fasteners.

Figure 1. Photo of Mrigadayavan Palace. Reprinted from Bangkok Huahin Taxi. (2017).

2.1.3 - The Mrigadayavan Palace Foundation

Over time, the value of the palace in terms of history, arts, and architecture had slowly deteriorated, therefore the Mrigadayavan Palace Foundation is currently working on a restoration project, for the purpose of restoring the palace grounds and the surrounding coastal vegetation. Since 1992, the mission of the Foundation has been to protect and conserve the historical, architectural, and environmental heritage of the palace, while simultaneously honoring and serving the conservation goals of King Rama VI and the late King Rama IX. The Foundation's vision is to restore the palace to its original condition, architecturally and environmentally comparable to when it was first completed in 1924. The Foundation aims to complete this restoration project by 2024, in time for the Palace's 100th anniversary, and the Foundation hopes that the palace will serve as a national heritage, a museum, a historical learning center, and a tourist attraction simultaneously.

2.1.4 - Previous Restoration Process and Challenges

After the passing away of King Rama VI in 1925, the palace was abandoned until King Rama IX gave permission to Naresuan Camp's Air Support Division to use the grounds of the Palace in 1965. Because the palace had been left empty for several decades, the paint has flaked off, exposing the wood, causing a lot of structural issues. It has been noted that the seaside buildings of the palace are more damaged than other buildings. The rooftop has cracked, resulting in rain causing damage to the interior parts of the buildings. Some of the columns have also given way, disrupting the palace's structural integrity. Therefore, many restoration projects were carried out, aiming to conserve the original beauty of the palace.

The Mrigadayavan Palace has undergone several restorations in order to preserve its architectural, cultural, and environmental heritage. In 1983, the Fine Arts Department and Border Patrol Police initiated the First Restoration project by rebuilding and repainting the palace. However, due to its proximity to the beach, the palace still suffered constant wear and numerous structural damages. Therefore, the Second Restoration project began in 2013. The purpose of this second restoration process is to restore the palace to its original state in order to preserve and conserve the original identity of the Palace. After conducting research and analysis, architects and archeologists discovered that there were many errors in the previous restoration, such as using the wrong color of paint and roof tiles that were too heavy. An ISSP Project from the previous year (Cohn et al., 2020) also dealt with the palace's brackish groundwater, which interfered with the restoration process.

2.1.5 - Nail Corrosion Problem of the Palace and Its Relation to the Community

Since the structure of the Mrigadayavan Palace is constructed with teak wood connected into columns, beams, and glens with metal nails, the weakening of wood around the old metal nails have been frequently observed. The wood surrounding the nail is usually stained black and rotten, allowing nails to be easily removed. These removed nails often come out with some wood attached to the shank, indicating that the internal structures of the wood have been damaged. Moreover, as the corrosion continues to progress overtime, the shank of the nail under the surface of the wood will corrode away, leading to further deterioration to the palace structure.

Originally, the Foundation intended to make the palace into a living museum where the community and visitors can come to study and expand their learning, rather than for it to be just a conventional museum that displays artifacts. The staff want to collect as much information related to the palace as possible to put on display for the benefit of those who are interested, as well as to preserve aspects of both nature and culture that the palace holds. However, due to the mentioned nail corrosion problem and also due to COVID-19, the palace was closed for repair since April of 2020. Thus, not only does the problem of nail corrosion affect the palace structure directly, it also affects the community living around that area and tourists since they cannot visit the palace and fulfill the Foundation's hope of making the palace a museum.

2.1.6 - Principles of Conservation

Conservation is defined as the process of managing change to a place in ways that will best sustain its heritage values, while also revealing the values for present and future generations. Thus, the principles of conservation can be viewed as a comprehensive framework for the sustainable management of heritage or historical sites that would benefit the place itself and also people in the community.

The main goal in the restoration process of the Mrigadayavan Palace in terms of social aspects is to conserve its original beauty and preserve its architectural, cultural, environmental, and historical heritage. The palace staff are trying to conserve the original materials that were used to construct the palace as much as possible, hoping that they would help reinforce the beauty and historical values of the palace. In order to achieve this, two important aspects need to be considered: authenticity and aesthetics. Authenticity can be defined as the truthfulness of a site to its original value, considering aspects of culture and community. It can be considered as the pride of the ancestors or a historical place for a culture to recall their collective experiences or memories. Meanwhile, aesthetics is defined as beauty or the way in which people draw sensory and intellectual stimulation from a place that can touch a viewer's heart (Drury & McPherson, 2008). In addition to these two aspects of authenticity and aesthetics, decisions about changes in the restoration project must also be reasonable, meaning that the restoration should benefit the heritage the most so that management can be done in a way that will sustain its values. The change should not harm or create any negative impacts to the heritage values of the place and should also benefit the palace itself and wider community or society as a whole.

2.2 - Composition of Wood

Wood is structurally a matrix of cell walls with open space called lumen. The chemical composition of wood varies between species and even between individual trees, depending on the part of the tree, type of wood, geographical location, climate, and soil conditions (Pettersen, 1984). The two major components of wood are carbohydrate and lignin with minor amounts of extraneous materials such as organic extractives and inorganic minerals such as ash.

The carbohydrate portion consists of cellulose, which is a polymer of glucose packed into layers that contribute to the strength of wood, and hemicellulose, which are a mix of polysaccharides that are intimately associated with cellulose and act as the structural component of plants. Lignin is a phenolic substance that acts similar to glue to hold the carbohydrates together, and leads to the rigidity and higher mechanical strength of wood. Structures of cellulose, hemicellulose, and lignin can be seen in Figure 2. The composition of wood should be understood in order to determine if specific chemicals in preservatives may affect or damage the structure of wood.

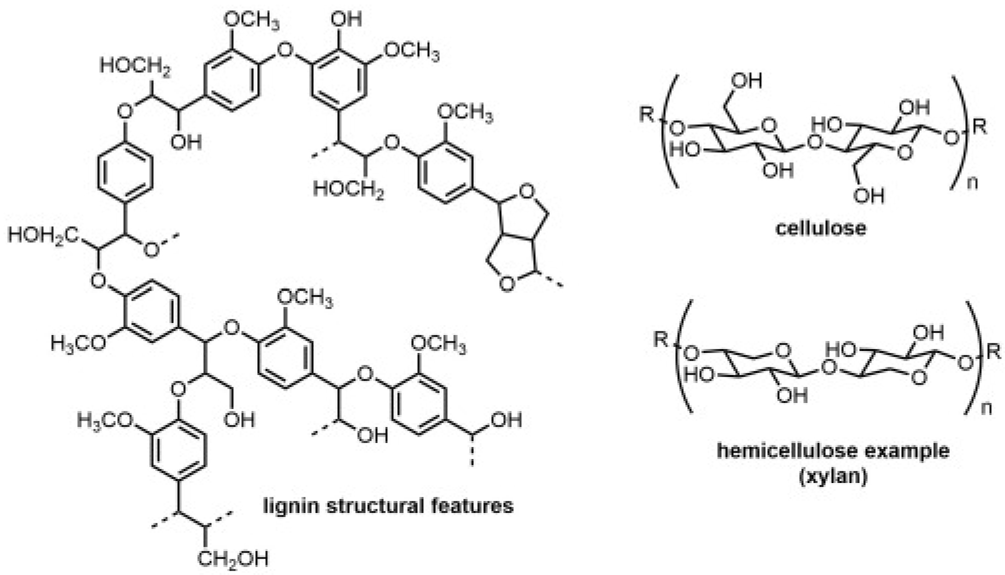


Figure 2. Chemical structure of cellulose, hemicellulose, and lignin. Reprinted from “Separation of cellulose/hemicellulose from lignin in white pine sawdust using boron trihalide reagents” by M. Kazmi, A. Karmakar, V. Michaelis, F. Williams, 2019, *Tetrahedron*, *75(11)*, p. 1466.

2.2.1 - Properties of Teak Wood

Teak, or *Tectona grandis*, is a type of deciduous, hardwood species, which grows in tropical climates and is native to south and southeast Asia. It is highly valued for its use in shipbuilding, outdoor equipment, furniture, and general carpentry. It is moderately hard and heavy, seasons rapidly, dries well in a kiln, and has overall good machining properties (Miranda et al., 2011).

2.3 - Composition of Nails

Nails are used in the construction process for the purpose of fastening objects, such as pieces of wood, together. The sharp-pointed end of a nail is called the point, the length of the nail is called the shank, and the flattened part is called the head. Nails are most commonly made of steel, but sometimes they can also be made of stainless steel, iron, copper, aluminum, brass, bronze, or nickel. However, the compositions of nails can vary, and they do not have to be made of a single type of metal. For example, steel nails are composed mostly of iron mixed with a small amount of other materials, such as carbon, to enhance the strength, corrosion resistance, or other desired properties of the nails. In addition, they can also be coated with chemicals such as zinc, in order to prevent them from rusting and for aesthetics.

2.3.1 - Stainless Steel Nails and Their Grades

For outdoor work, stainless steel nails are considered to be the best type to use in order to reduce the occurrence of rust on wood (Rapczynski, 2018). Stainless steel is an alloy of iron and some other elements such as chromium and carbon. Since maintaining the original structures and beauty of Mrigadayavan Palace is one of the purposes of this project, minimizing the chemical reaction between minerals in nails and wood by selecting the right types and grades of nails for usage is very important because stainless steel nails come in different grades.

Stainless steel type 304 is considered a good grade stainless steel nail, and they are made with 18% chromium and 8% nickel (Bohn, 2012). These nails will work better for indoor applications than general stainless steel nails because they provide a higher quality of protection from rust. Also known as rust-resistant nails, stainless steel type 304 nails are suitable for the usage in the absence of moisture or humidity. Therefore, they are potential candidates for indoor applications.

Another good grade of stainless steel is stainless steel type 316. Nails made from this grade of stainless steel contain 16% chromium, 10% nickel, and 2-3% molybdenum, which makes them rust-proof (Bohn, 2012). With this special composition and their properties, they can be used for both indoor and outdoor functionalities. Additionally, this unique rust-proof property provides a variety of applications, including uses underwater, above the ocean, or even in salt water. Usage of this grade of nails include the use on boats and any natural wood outdoors (Rapczynski, 2018).

2.4 - Possible Causes of Corrosion of Metal in Wood

2.4.1 - Mechanism and Reaction of Corrosion

Corrosion is a reaction that occurs between the minerals in the metal nail and the minerals in the wood (Rapczynski, 2018). Corrosion in wood is an aqueous process, which means that it occurs in the free water present in cell walls and in lumens at higher moisture contents. However, the occurrence of this aqueous process is not spontaneous, and the moisture content in wood should be above the threshold, between 15% to 18%, in order to initiate the process.

Rust, a reddish-brown compound known as iron oxide, is a type of corrosion that results from the oxidation of iron in the presence of both oxygen and moisture. Weakening of wood is commonly observed in wood that is surrounded by corroding metal, due to corrosion when wet wood becomes slightly acidic. When metal nails are embedded in wet wood, the acceleration of metal corrosion can occur at a faster rate, deteriorating the wood that surrounds them, and also decreasing the holding ability of the nails.

Due to the corrosion of metal nails and the degradation of wood being common occurrences, much research on the chemical analysis and physical properties of wood in contact with corroding iron has been conducted. A.J. Baker (1974), a chemical engineer of Forest Products Laboratory at U.S. Department of Agriculture, reports that the corrosion of metal nails in wooden structures is due to the oxygen concentration gradients between the exposed end of the nails to the air and the end embedded into the wet wood. The reason why a metal corrodes in wet wood can be explained by using the theory of electrolytic corrosion.

The corrosion of a single metal fastener in moist wood can be considered as crevice corrosion, which means that the corrosion occurs through a crack within the wood structure. The exposed head acts as the cathode, and the shank of a nail acts as the anode of a galvanic cell. The exposed end of the steel nail in wet wood exhibits the activity of hydroxyl ion (OH^-) formation. The chemical reaction at the cathode where reduction occurs can be written as:

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$$

The reaction at the anode where oxidation occurs can be written as:

$$Fe \rightarrow Fe^{2+} + 2e^-$$

These ferrous ions (Fe^{2+}) at the anode are active and can further oxidize to form ferric ions (Fe^{3+}). Moreover, the reaction can form either black iron tannate dyes, when these ions react with tannic acid naturally found in small amounts in wood, or rust when these ions react with oxygen and water. Therefore, these iron ions can be viewed as active catalysts that can promote chemical reactions, causing the loss of strength to the cellulose and the internal structure of the wood.

2.4.2 - Catalysts and Accelerators

Apart from the reaction of metal corrosion, there are also accelerated conditions where some chemical species can help to speed up the corrosion process. The soluble chlorides that are present mostly in natural waters can form acidic conditions around the metal nails in wet wood, resulting in the accelerated corrosion of the nail and the weakening of wood. During the progression of the reaction between the exposed head of a nail as the cathode and the shank of a nail as the anode, the chloride ions (Cl^-) and the hydroxyl ions (OH^-) will migrate into the crack between the wood and metal nail as shown in Figure 3 (Baker, 1974). After the formation of ferrous ions (Fe^{2+}) at the anode, these ions will react with hydroxyl ions (OH^-) from the water inside the wood crack, forming insoluble iron hydroxide in the crevice. Furthermore, the decrease in the concentration of hydroxyl ions (OH^-) will lead to a higher amount of hydrogen ions (H^+) present in the system. Due to the accumulation of chloride ions (Cl^-) and hydrogen ions (H^+), this causes the solution to become acidic. As a result, the acidic solution inside the crack will speed up the corrosion process, promoting the hydrolysis of cellulose in the wood, which weakens the surrounding wood.

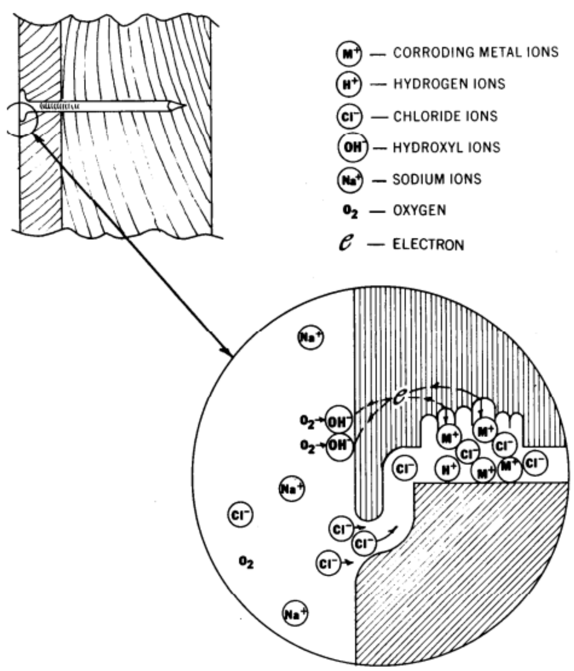


Figure 3. Schematic for the mechanism of crevice corrosion. Reprinted from *Degradation of wood by products of metal corrosion* by Baker, A. J., Forest Products Laboratory (U.S.), & United States. (1974).

2.4.3 - Effect of Seawater on Wood and Metals

Seawater can damage the structure of metal nails. The corrosion process of seawater is dependent on alloy composition, pH, microbiological organisms, pollution and contamination, temperature, and oxygen content. The process by which seawater damages nails and wood can be categorized and explained in two parts, which are chloride ion activity and dissolved oxygen activity. Without water and oxygen, the rusting process cannot occur.

The reason why salt water has more effect on catalyzing the rusting process than that of fresh water is the ease of current flow. Salt water is an electrolyte solution, which means it contains more dissolved ions than fresh water. Chloride ion (Cl^-) content in salt water is high due to the dissociation of salt, or sodium chloride, in water. Thus, salt water can accelerate the rusting process as described in the previous section.

2.4.4 - Different Types of Rust and Their Formations

Rust can occur in many colors in relation to the humidity and oxygen content in the surrounding environment. By understanding the different conditions that lead to the formation of rust and being able to identify the types of rust, the root causes of the rust problem may be found.

Rust can be divided into four different types, which are red, yellow, brown, and black rust, and each type of rust is formed under different conditions (Armor Protective Packaging, 2019). Red rust (Figure 4a), also known as hydrated iron(III) oxide ($Fe_2O_3 \cdot H_2O$), can be formed due to high exposure to oxygen and water. This type of rust usually occurs uniformly on the surface. The formation of yellow rust, or iron(III) oxide-hydroxide ($FeO(OH)H_2O$) as shown in Figure 4b, generally occurs in areas where there is high moisture content. It can be present on metals that are found in large amounts of standing water such as near sinks or bathtubs. However, the presence of this yellow rust is not currently observed around the palace areas.

Brown rust, or iron(III) oxide (Fe_2O_3) (Figure 4c), is formed in conditions where there is high oxygen and low moisture. Lastly, Figure 4d displays black rust, or iron(II,III) oxide (Fe_3O_4), which can occur in areas of limited oxygen and low moisture content. This type of rust can be visually identified as a stain or a thin, black film. Compared to other types of rust mentioned, black rust does not propagate or corrode as rapidly as others.

Figure 4a. Photo of red rust. *Figure 4b.* Formation of yellow rust on metal parts. Reprinted from *Types of Rust* by Armour Protective Packaging. (2019). *Figure 4c.* Photo of brown rust. *Figure 4d.* Photo of black rust.

2.5 - Deterioration of Concrete by the Corrosion of Reinforcing Steel Bars

Currently, apart from the corrosion of metal nails in the wood, another major problem that the palace staff are concerned about is the corrosion of the reinforcing steel bars inside the concrete columns, which could further lead to the deterioration of the surrounding concrete itself. Signs that indicate the rusting of reinforcing steel bars are usually stains and cracks on the concrete surface. Once rusting of the internal steel bars happens, the internal steel bars will get thicker and their volume will increase, which leads to the expansion in size that will further create tensile stress within the concrete structure. As a result, this can eventually cause cracking, spalling, and deterioration of concrete (Portland Cement Association [PCA], n.d.).

Figure 5. Photo of cracking and spalling of concrete columns around the palace area.

Normally, the alkaline environment of concrete, with pH around 12 to 13, that covers the reinforcing steel will provide protection against corrosion to the steel. A thin oxide layer (Figure 6) will form on the steel at a high pH, acting as a passive film to reduce the corrosion of steel to an insignificant level (0.1 μm per year) (PCA, n.d.).

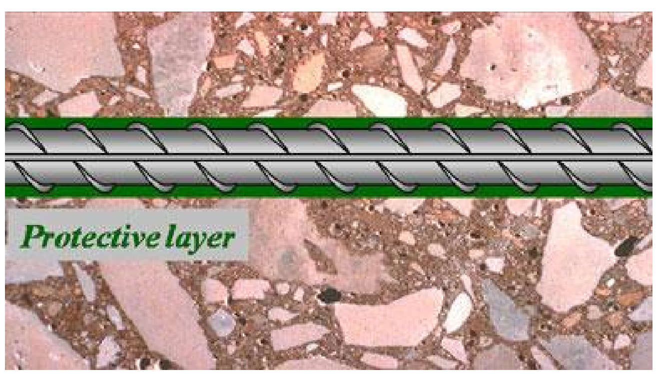


Figure 6. Representation of a thin oxide layer forming on the steel as a protective layer. Reprinted from *Corrosion of Embedded Metals* by Portland Cement Association. (n.d.).

The causes of corrosion of the reinforcing steel are primarily due to the penetration of water, carbon dioxide, and chlorides, and the lack of adequate thickness of concrete covering the steel (Komchadluek, 2019). Whenever there is a crack on the concrete surface, water, chlorides, and gases such as carbon dioxide and oxygen will be able to penetrate inside, causing rust to occur. Carbonation is the process that occurs when carbon dioxide penetrates the concrete and reacts with hydroxides, such as calcium hydroxide, to form carbonates. The chemical reaction of how this process occurs can be described as:

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

When carbonation occurs, the pH inside the concrete column will be reduced due to the decrease of calcium hydroxide, which is more basic than the calcium carbonate that is formed. Additionally, the cause of reduction in pH also comes from the reaction of carbon dioxide in the presence of moisture, producing carbonic acid (Shaker & Reddy, 2009). This causes the environment surrounding the steel bars to become less alkaline and the passive film on the steel to become unstable. Once the passive layer is destroyed, the steel bars will no longer be protected, and as a result, rust can more easily form on the steel bars.

Moreover, similar to the corrosion process of nails in the wood, chloride ions from sea salt spray, along with oxygen and moisture, play important roles in accelerating the corrosion activity. However, the actual process of how chloride ions corrode steel is still not completely understood and proven. The most popular theory is that chloride ions can penetrate through the protective layer of oxide film easier than other ions, which makes the steel prone to rust (PCA, n.d.).

2.6 - Fungi

Fungi are natural decomposers that need water and nutrition for growth. Organic compounds such as wood are a fungi's main source of nutrition. Since the Mrigadayavan Palace is mostly made from teak wood and located by the seashore, it is a suitable place where fungi can grow.

Fungi can reproduce both sexually and asexually, starting from the mycelium, which is made up of a network of thread-like hyphae that contains genetic information. Fungi that reproduce asexually will perform mitosis to release spores, which are genetically identical to their parents. In sexual reproduction of fungi, two haploid mycelial cells will fuse together. Then, the two nuclei will fuse to form a diploid nucleus. Then, the new cell will perform meiosis and release haploid spores. Finally, spores from both asexual and sexual reproduction can germinate, or grow, into new haploid mycelia (Figure 7) (Clark et al., 2018).

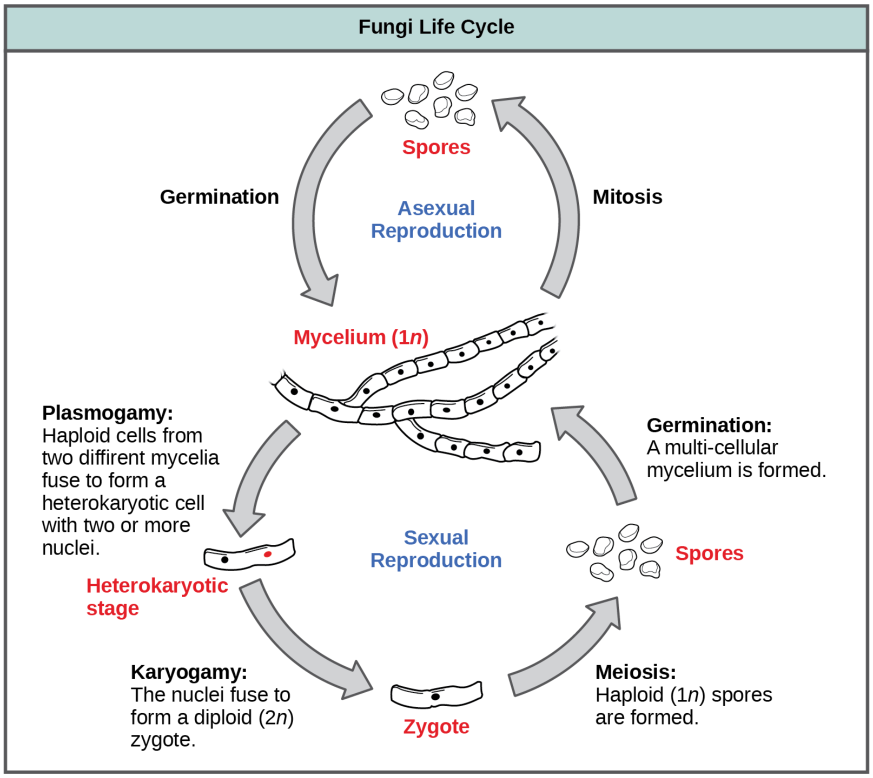


Figure 7. Generalized life cycle of a fungi. Reprinted from “Characteristics of Fungi” by Clark et al. (2018).

Ascomycota and Basidiomycota are possible divisions of fungi that could grow in the palace environment, since both species can be found in marine areas with a tropical dry ecosystem. They are perfect fungi, which means that they can reproduce both sexually and asexually, and they are harder to remove than fungi that only grow asexually (Clark et al., 2018).

Fungi can destroy cellulose and lignin in the cell wall of plants. Fungi in different areas can be connected through a mycelial network, and the mycelia can transfer water from damp areas to deliver to drier areas. Once the mycelium becomes stronger, it turns black due to melanin, which helps protect fungi, making it harder to remove. Fungi can also withstand high temperatures up to 60 °C and can grow in only 20% humidity content in the air (T. Kriangkripipat, personal communication, Jan 27, 2021).

There is also growth of fruiting bodies (Figure 8) on some wooden structures in the palace area. Fruiting bodies are structures of fungi made from an interwoven network of mycelia that can appear during sexual reproduction to produce and disperse spores. As mentioned earlier, the presence of mycelia is a sign that the reproductive cycle has been carried out, which means that the growth of these fruiting bodies is an indication that the structures in that area have been neglected for a long time, and they are also harder to remove (T. Kriangkripipat, personal communication, Jan 27, 2021).

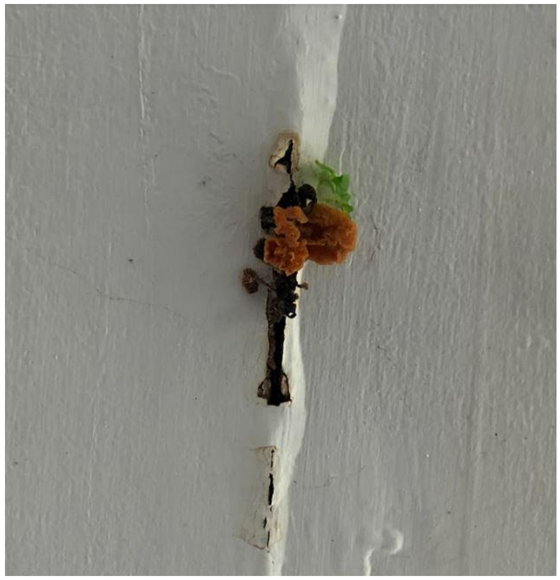


Figure 8. Photo of growth of fruiting bodies on the wooden structure at Mrigadayavan Palace.

2.7 - Prevention and Preservation Attempts

Various methods for prevention of rust in order to preserve wood are described.

2.7.1 - Wood Preservatives

Wood preservatives are chemicals that are coated onto wood to help reduce decay, prevent attack by fungi and insects, or increase flame retardance. However, some wood preservatives are corrosive or contain catalysts for corrosion. Creosote, or tar oil, is an oil-based preservative, which shows little corrosive action except in lead. Oil also causes the wood to be waterproof, which helps reduce moisture in the wood. It is usually used in the outdoor area of the building since it has a strong scent, and it also stains the wood, so it is not widely used. The most widely used wood preservative is copper chrome arsenate (CCA), which contains copper ions that can potentially be corrosive in wood. Organic solvents such as pentachlorophenol and lauryl pentachlorophenate are water repellent and have a negligible effect on corrosion, but alkali conditions may cause them to release chloride ions. Flame retardants are salts that are added to reduce the combustion of wood. These salts may contain ammonium phosphate, ammonium sulphate, boric acid and borax, with ammonium sulphate being considerably corrosive. These salts will also increase the moisture content of the wood when in contact with air (National Physical Laboratory, n.d.).

2.7.2 - Technologies for Wood Preservation in Historical Monuments

Wood has been a commonly used material for buildings in history, thus there have been many attempts of wood preservation throughout history. Therefore, by studying wood preservatives that are used elsewhere to protect historical buildings, insight on some preservative methods may be adapted for use in the palace.

Larsen and Marstein (2000) documents how people in the past preserved their wooden structures. The Chinese used paints mixed with materials both of natural and chemical nature, Greeks and Romans used resin and oil extracted from timbers to protect their wooden structures, and in Indonesia, a country with a similar hot and humid climate to Thailand, a wood preservative for their teak wood structures was made by using a solution of tobacco or cloves with water, and directly brushing the solution, which is both an insecticide and fungicide, onto the wood.

Another documented case of wood preservation of historical monuments is the preservation of totem poles in Sitka National Park, Alaska by Sheetz and Fisher (1993). The wooden totem poles have been subjected to fungal and insect damage, and they have gone through various treatments for preservation. The most effective method was the use of borates and oil-based water repellent. Borates provide protection from insects, brown rot, white rot fungi, and they are safe for people and the environment. The disadvantages of borate preservatives are that the compounds have a tendency to leach out of the wood, and they are not effective for mildew and soft rot fungi. The borates were used in tandem with oil-based water repellents brushed along the wooden surface, and wood putty made from epoxy and fumed silica was used to fill in any minor cracks in the totem pole structure. The fumed silica is commonly used as a thickening agent for resins such as epoxy (Barthel et al., 2002). This allows the wood putty to settle properly into the cracks of the totem pole.

2.7.3 - Cathodic Protection of Nails

In order to prevent crevice corrosion, the main reaction that causes the wood to deteriorate, Baker (1974) suggests that nails fastened in wood should be countersunk and covered with plugs of the same wood species. Additionally, since metal corrosion can occur from dissimilar metal nails, different types of metals should not be used together, thus if both washers and nails are used, they should be the same type of metal.

Cathodic protection of metals can also be used, but it must be done with care. Cathodic protection is performed by connecting the nail to be protected to another sacrificial metal by a conducting wire. The sacrificial metal, such as zinc or magnesium, will act as an anode and corrode in place of the nail. However, the nail, now acting as the cathode, can still produce alkaline conditions, corroding the wood surrounding the nail, but not the nail itself. If these suggested preventive measures can be performed, they are expected to reduce the severity of corrosion to some extent.

2.7.4 - Curing of Nail Rot and Rust

Since corrosion between wood and nails can be initiated from the rusting of metal, the following solutions to cure nail rust are proposed. Coating is the process of the application of a protective layer of chemical, commonly zinc, onto nails in order to avoid rusting. By coating iron with a shielding layer of zinc, this can stop the rusting process, since zinc can act as a barrier to stop the reaction between iron, oxygen, and water. This process of applying a zinc layer is called galvanization. Additionally, some specially manufactured paints can also be used to stop salt water from rusting the metal.

According to Figure 9, which shows the estimated service life of zinc-coated steel in different environments, corrosion tends to occur in coastal areas the most, and the range of lifespan for galvanized metal is shortest. Zinc coatings will be consumed faster in more corrosive environments, especially in the seaside areas, and the nail will start to rust due to the exposed layer of iron.

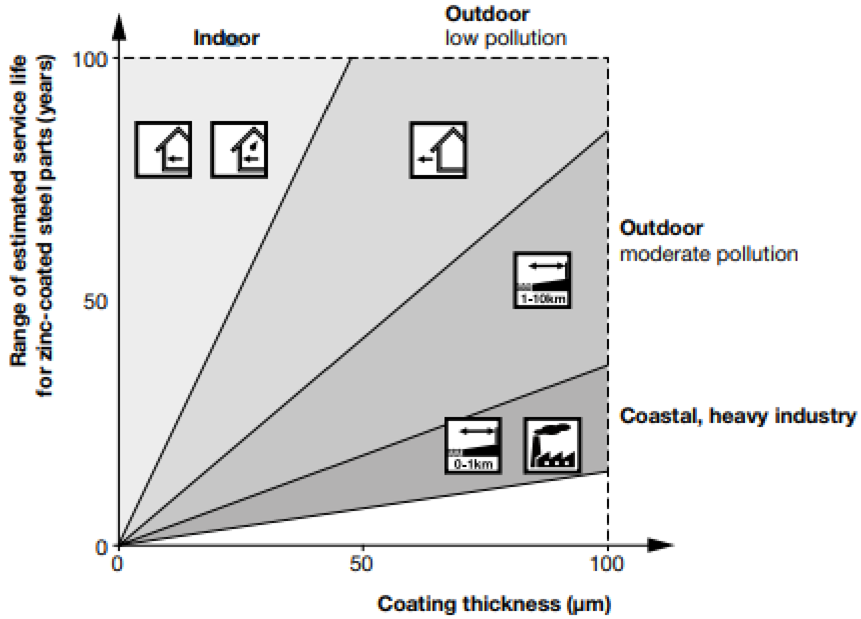


Figure 9. Typical service life of zinc-coated steel in various environments. Reprinted from *Corrosion Handbook* by Hilti Corporation. (2015).

According to MakeWoodGood (2018), detailed steps on how to prevent the spreading of rust is discussed. Mainly, nails and stained wood will be treated with Jenolite, a water-based chemical solution that contains two main active ingredients: phosphoric acid and an organic polymer. The phosphoric acid in the Jenolite will convert rust (iron oxide) into an inert layer of ferric phosphate, which will appear black. This inactive layer acts as a protective layer against further rusting. After Jenolite is applied, dry the wood thoroughly again and wood preservatives or paints can be applied later for aesthetics. However, if the nails and wood are too rotten to be repaired, replacement should be done instead.

2.8 - Test Methods for Corrosion Monitoring

A research paper by Zelinka and Rammer (2005) suggests three types of test methods for the evaluation of corrosion of metals in contact with wood: exposure tests, accelerated exposure tests, and electrochemical tests.

Exposure tests are the easiest test to run, but take a long time because metals to be tested for corrosion are left in wood in the same conditions that they will be used. Accelerated exposure tests were invented to accelerate the simpler exposure tests by increasing the corrosiveness of the environment around the wood by raising the moisture or temperature, and an example is the salt-spray test. Electrochemical tests aim to measure the current density at which corrosion takes place, then current density can be converted to the mass lost. However, electrochemical tests require expensive equipment and deep knowledge about electrochemistry, thus they may not be a suitable monitoring test for non-scientist staff at the palace.

If a test to monitor corrosion that is simple to perform can be discovered, then the palace staff can perform that test to monitor corrosion of nails in the palace. However, if no tests are suitable, then a monitoring system should be set up to systematically monitor the effects of corrosion.

Chapter 3 - Methodology

The goals of this project are to understand why metal nails and reinforcing steel bars cause corrosion in wood and concrete, understand how fungi grow in wood, identify methods to prevent rust and fungi from causing deterioration in wood and concrete of the Mrigadayavan Palace, as well as to design a monitoring program to monitor the effects of different solutions that are applied. In order to accomplish these goals, the team proposes the following objectives:

1. Assessing the extent of the problem of corrosion in the palace buildings
2. Understanding and identifying the most suitable methods of corrosion prevention, fungi removal and prevention, and wood preservation
3. Initiating a monitoring program to monitor the effectiveness of preservative methods, record progression of corrosion, and plan for future maintenance
4. Summarizing and presenting information for the benefit of the public

3.1 - Objective 1: Assessing the Extent of Corrosion

In order to be able to efficiently evaluate the root causes and the severity of the corrosion process, the team performed empirical research by visiting the palace to study the impact of the problem. By qualitatively observing different areas of the palace where corrosion and fungal growth occurs, general areas of damage ranging from least severe to most severe were pinpointed. Figure 10 displays the layout of all the structures of the palace in a grid system.

Additionally, with the help of information provided by the palace staff and conversations with expert scientists, scientific and historic information was extracted. The information includes the detail on the geography of the location of the palace and surrounding areas, the changes made to the palace in previous restoration processes, and the information on the concentration of salt in the bodies of water in the area measured frequently by experts there. Therefore, by observing and assessing the extent of corrosion in the area, the current condition of the palace was better understood.

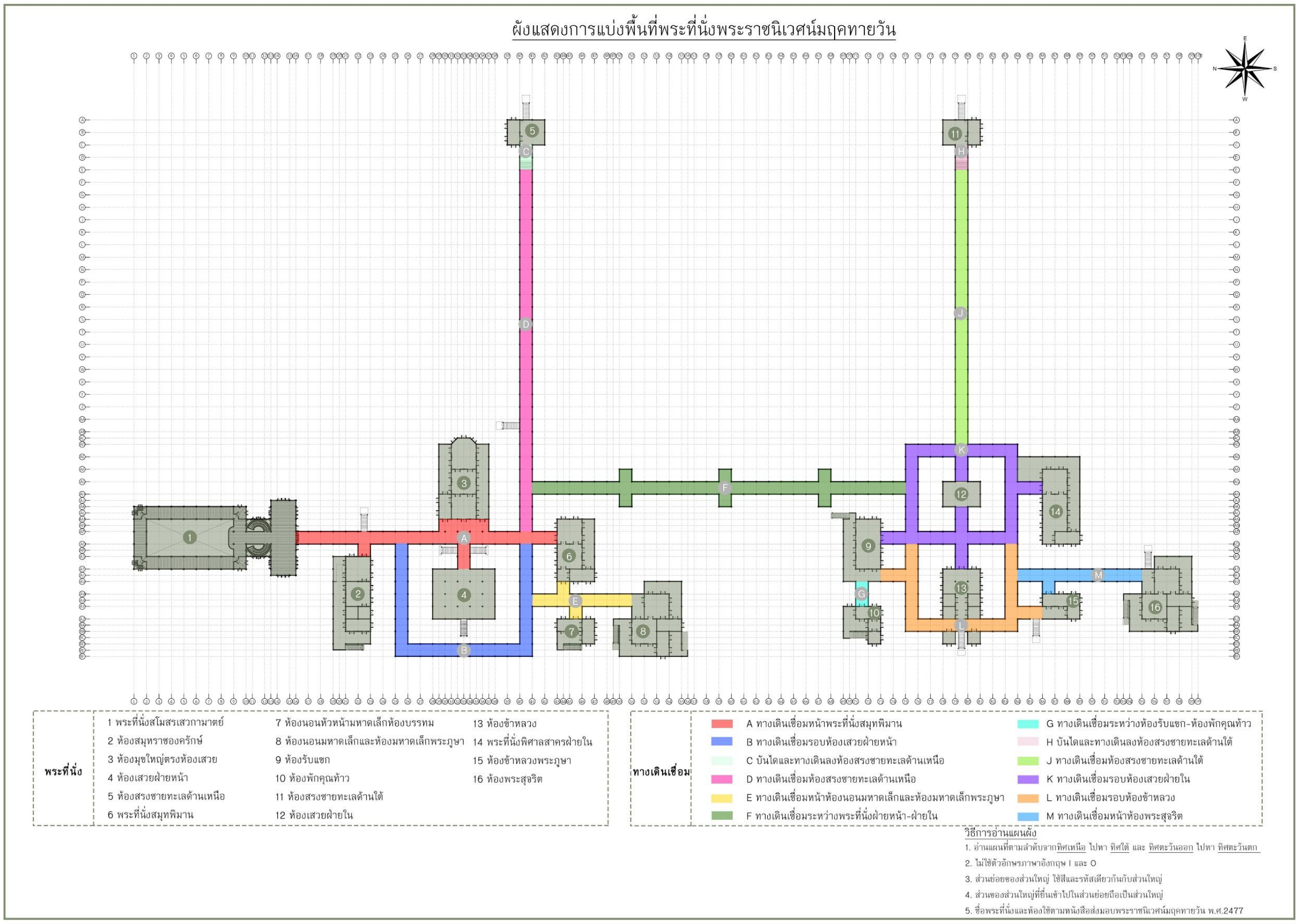


Figure 10. Diagram of Mrigadayavan Palace. Provided by the palace staff.

Apart from observing the actual location, our team kept up with the situation and condition of the palace by frequently contacting and communicating with the palace staff to receive more updates and clarification. This greatly assisted our team in researching and literature review, since we were able to narrow our scope of research on certain topics, fill in gaps that were still missing, and found useful solutions to propose to the staff who are working on restoration.

3.2 - Objective 2: Understanding and Identifying the Most Suitable Methods of Corrosion Prevention, Fungi Removal and Prevention, and Wood Preservation

To identify methods of prevention of rust and fungi and preservation of wood in the Mrigadayavan Palace, the team performed further background research on preservatives that have been tested and published in research papers by other scientists and case studies from the preservation of structures in other countries. We attempted to find research papers and case studies from countries that are similar to Thailand in terms of climates and environmental conditions, so that they could be adapted and used with our project. In accordance with the Palace Foundation's wishes to preserve the palace to the best of their ability and according to the principles of conservation, the methods of preservation that the team suggested to the sponsor should keep the palace authentic and aesthetically pleasing. Thus, in order to be considered a suitable method for suggestion, it should not be harmful to the wood and nails, it should not lead to further problems in the future, and it should be environmentally friendly or minimally harmful to the environment.

However, complications arise when preservation methods have to be suitable for application on all types of materials used in the palace including nails, fungi, wood, and concrete. For example, a method used to clean rust from nails may stain the wood, which would not look aesthetically pleasing, or another method used to preserve wood may not be protective against fungi in the long run. Thus, any method found was not suggested to the palace staff without considering all its effects.

For preventing further rusting and preserving new metals from rust, the mechanism of rusting was understood by the team. Research on different types of rust observed at the palace was performed to further understand rust. After we understood the process of rusting, research was carried out on rust prevention methods, including possible nail replacement and some possible methods to remove rust from metal and concrete. The main concern about rust from the staff was to prevent areas that are waiting to be restored from further deterioration by rust in both wood and concrete columns.

In order to discover methods for fungi prevention, the team began by understanding the life cycle of fungi and studying possible species of fungi that can grow in Thailand. Then, our team focused on researching the root causes of fungi, their growth, and their removal in order to further understand fungi. Since fungi can cause wood to deteriorate, methods used to clean fungi and prevent them from destroying the wood were also researched.

After initial observation of the palace, older wood preservatives that have been used seem to be ineffective, therefore the team performed research on wood preservatives that could be effective for a long time by looking through case studies from other countries on how they preserve their wooden structures and determining if those preservatives would be applicable in the case of the Mrigadayavan Palace. Additionally, since the preservatives used should be minimally harmful to the environment, greener approaches to wood preservatives were also explored.

The team contacted and interviewed experts in these fields, such as professors with expertise in areas of fungi or concrete, and carpenters and craftsmen that have experience working with wood. Furthermore, our team talked and discussed with the palace staff often to gain updates about the restoration project and to suggest some of the methods we researched to gain suggestions and comments from them.

During background research, when potential preservative methods were found, these methods were compiled together and thoroughly analyzed for compatibility with iron, fungi, wood, and concrete. If a method was detrimental or harmful to one of these aspects, then it was not considered as a suitable suggestion for the palace staff. Aspects such as cost, ease of application, and toxicity to humans and the environment were also considered. A chart of preservative methods with the most potential and their effects on different materials were then presented to the sponsor.

3.3 - Objective 3: Initiating a Monitoring Program

According to observation by the team and information provided by the sponsor, currently there is a salt water monitoring program being operated by the staff, where different bodies of water in many locations are measured for their salinity. The salinity of freshwater should not have a value of over 0.2 ppt. From the monitoring, the result has shown that the inland water has started to increase in salinity, meaning that salt water has flown inland from the ocean and cannot flow out as easily. The monitoring of salt content is important because the salt spray in the air does not come from only the ocean, but also from inland, and the presence of chlorides from salt can accelerate the problem of corrosion.

As a result, another monitoring program relating to preserving wood, nails, and concrete should be initiated. More literature review was done on how rust and fungi in wood is monitored in historical buildings elsewhere. The monitoring program should be easy to perform by non-scientist staff and cost-effective as per request of the sponsor. The monitoring should also indicate whether rust or fungal growth has started to occur on the surface of wood. Exploring humidity, temperature, and salt content in the air was also beneficial, due to these being major factors in initiating and accelerating corrosion.

Thus, our team designed a simple monitoring program in the form of a chart in order for the staff to record and keep track of data. This would be greatly beneficial to the palace staff because they have been testing recommendations for preservation methods from other sources, but they are unsure of how to monitor the lifetime or the efficiency of these methods. Thus, by using the monitoring chart, the palace will have documentation on all the necessary factors and plan for any maintenance they have to perform in the future before new areas of corrosion or fungi growth can destroy more of the palace.

3.4 - Objective 4: Presenting Information for the Benefit of the Palace and the Public

In accordance with the Mrigadayavan Palace Foundation's wishes to have the palace serve as a museum where visitors can learn about culture, nature, and history, we summarized the knowledge gained from our research and presented it in an attractive way for the palace staff to use to show the public. Once all the suitable methods were processed and acquired to solve the problems and the monitoring system was ready, this information was then summarized and presented to our sponsor to explain the causes of nail corrosion in teak wood, methods for rust prevention, suitable wood preservatives, and the set-up of a monitoring system for corrosion.

Afterward, the information was also designed into the form of infographics, which would make the information more interesting, understandable, and attractive to the public. This will be done by discussing with the palace staff about visitors' opinions and what they plan to use it for. This will help our team know what information should be included into the infographics. The infographics summarized the knowledge gained in a way that is easy to understand by people in non-scientific fields so that other members of the foundation, visitors, or even children are able to learn from and be able to access the information obtained in the report.

Chapter 4 - Results and Analysis

4.1 - Finding 1: Different areas of the palace are affected at varying levels of severity depending on the proximity to the ocean

From our visit to the Mrigadayavan Palace, our team observed and took pictures of different areas of the palace that contained signs of deterioration. After mapping the locations where rust or fungi occurred on the provided diagram (Figure 10), we found that the palace structures closer to the ocean were affected by rust and fungi more severely than structures found inland. Black fungal stains were found covering the floor of the pavilion close to the ocean. Rust was also found to have spread into a wider radius onto the wood on the walkway leading to the ocean when compared to rust in structures closer inland. We also found that wooden planks that were close to trees were deteriorating due to the humidity released from the trees. The mapped results can be seen in further detail in Appendix A.

4.2 - Finding 2: The problem of rust stems from the carelessness and lack of thorough understanding of the consequences of previously used restorative methods

This finding resulted from observing the different areas of the palace, discussing with palace staff, and also performing additional literature review. We then analyzed the information gained by comparing the structures after restoration previously performed to the original structures before restoration. From the comparisons in both Figure 11 and Figure 13, the result shows that the restoration methods seem to be incorrect and ineffective as we can see that the original structures show no rust.

For the wooden floor at the palace, there is no presence of rust in the original structure because when the palace was first built, the nails were inserted inside the wooden planks, thus the nails were not exposed to oxygen, water, and chlorides. In a previous restoration attempt, when workers found wooden planks that started to stick out, they simply hammered those planks down with new nails, which are exposed to previously mentioned agents that can cause rust (Figure 12). Similarly, for the concrete columns (Figure 13), the original columns were made purely from concrete with no internal reinforcement bars. However after previous restoration, about 10% of the columns now contain internal rebars, and some of them are heavily deteriorated due to the corrosion of the reinforcing rebars inside. This indicates that restoration was not done correctly as well as the carelessness and lack of understanding towards the consequences of these restoration methods used.

Figure 11. Comparison of original wooden floor (left) and structure after previous restoration (right) of wooden floor. Reprinted from *The Restoration Management of Mrigadayavan Palace* by Sakunjaroenpornchai, P. (2017).

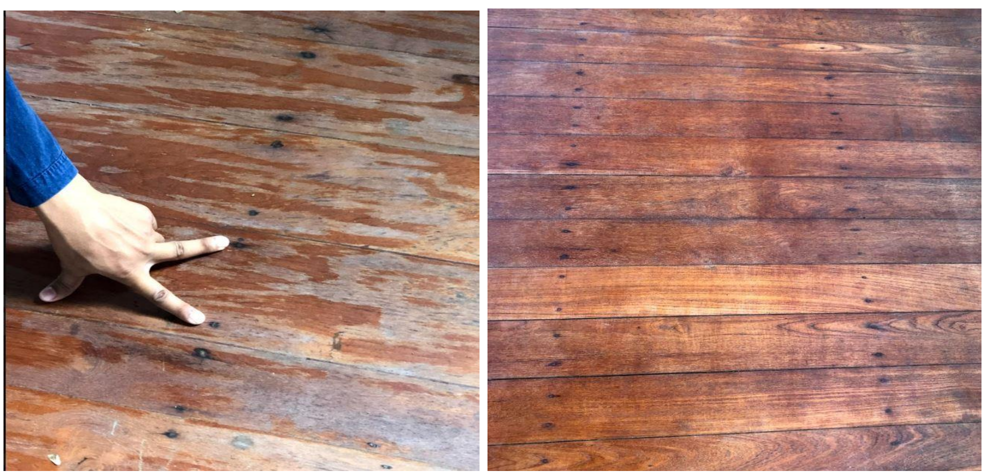


Figure 12. Photos of wooden floor at Mrigadayavan Palace after previous restoration.

Figure 13. Photos of concrete columns without internal rebars (left) and with internal rebars that have rusted (right).

4.3 - Finding 3: Fungi is a recurring problem due to the lack of interest in making sure the wood has completely dried before applying wood products

Our team observed the palace as well as talked with palace staff to see and understand the severity of the problem of fungi. We also looked through different research papers and interviewed an expert to discover the causes that could initiate the growth of fungi. We have understood that fungi is a decomposer that needs water and nutrition to grow. Since the palace is located on the seaside, the humidity from sea water is a major cause for high moisture content in wood. There are also many large trees around the palace, which can release humidity to nearby wooden planks. This causes the wood to absorb moisture, contributing to the growth of fungi (Figure 14). Additionally, puddles of water can also be seen on the palace floor (Figure 15), contributing to increased moisture in wood. Therefore, we can conclude that the wooden structure of the palace that contains high humidity content can act as a suitable nutrition source for fungi.

Figure 14. Photos of wet wood and the growth of fungi at Mrigadayavan Palace.

Figure 15. Photo of puddles of water on the palace floor.

In order to eliminate this problem, wood has to be thoroughly dry. However, according to conversations with the palace staff, a proper method of drying wood is not performed. Wet wood is only left to air dry. After a few days, the surface of the wood may feel dry, but the inside of the wood still contains moisture. From the leftover moisture, fungi can eventually grow back. Therefore, it is important that the process and the conditions for drying wood are controlled, and according to an interview with an expert, the most efficient way to dry the wood is to dry wood in a kiln or oven.

4.4 - Finding 4: Not all methods that were researched were viable or compatible with all materials

The team researched and interviewed various experts on different preservation methods to be used with nails, wood, and concrete and compared those methods together, considering whether chemicals suggested in different methods could be used with all the materials. We also considered different factors such as cost, toxicity, and effects to the environment and compiled all the methods into a table (Appendix B). This was a systematic way to compare and contrast the effects of various factors of each method.

For example, from the research on wood preservatives, we found that CCA and CCB are two suitable methods that could be used to protect the wood. However, from an interview with professor Songklod Jarusombuti, he suggested using MCA and ACQ due to their long service life and good retention in wood. We then did further research on these preservatives mentioned and from further analysis, we then concluded that MCA would be the most suitable wood preservative to use outdoors because CCA has high toxicity, CCB can leach out of the wood when in contact with water, and ACQ can corrode metal fasteners at a faster rate compared to MCA.

4.5 - Finding 5: The palace does not have an organized or systematic monitoring program

Through discussions with the palace staff, we discovered that the palace does not have an organized monitoring system. Areas of corrosion or deterioration are only noticed if a staff member notices and reports what they saw. There is no system to track the effects of products that are applied to wood or the growth of rust on nails. Therefore, our team thinks that designing a series of monitoring forms and logs would help keep information organized and on a constant check-up schedule. Since there are few permanent foundation staff, and those who are involved with restoration are constantly changing, manuals and guides were provided for each form for those who would be unfamiliar with these forms. The forms were refined several times to be more user-friendly to staff who do not have a scientific or technical background, and examples of some forms are attached in Appendix C.

4.6 - Finding 6: The palace does not have an exhibition dealing with scientific and restorative aspects

From conversations and discussions with palace staff, currently the exhibition at the palace only contains information about the palace's history and culture. Thus, our team thinks that integrating scientific knowledge into the exhibition would be interesting for visitors and the public, and this would also help with the plans to expand the exhibition to cover wider areas of knowledge for the palace museum and learning center. Therefore, our team designed infographics based on the information gathered during this project in both English and Thai. Additionally, to adapt to a digital age, QR codes of each infographic were also created, which can be implemented into the actual palace structure rather than just being displayed in an enclosed room. The designed infographics and the implementation of QR codes are shown in Appendix D.

Chapter 5 - Recommendations

In order to help lessen the severity of the problems, the team looked through different research and studies and found some recommendations on rust prevention, fungi removal and prevention, wood preservation, and a monitoring system. We hope that these recommendations would contribute to restoring the palace back to its original structure and would also benefit the palace in the future.

5.1 - Recommendations on Rust Prevention

5.1.1 - Removal of Rust

The methods of removing rust (Appendix B) are mostly natural, and the materials can be readily found in the market. These methods can be used to remove rust from metal, the internal reinforcement bars of concrete, and rust stains found on concrete surfaces. However, vinegar, lime, and oxalic acid are acidic in nature, which can cause iron to rust again. Therefore, after these methods are used, the area should be cleaned thoroughly with water to remove these acids.

5.1.2 - Prevention of Rust Using Tannic Acid

Tannic acid is a natural rust inhibitor which can be used to help prolong the corrosion and prevent further rusting of the materials, and more details of tannic acid are available in methods to prevent rust in Appendix B. Additionally, tannic acid also has an antifungal property, as discovered by Zhu et al. (2019). When testing tannic acid with *Penicillium digitatum*, a species within the Ascomycota division of fungi which may be in the same division as the fungi found in the palace as discussed in section 2.6, the growth of *P. digitatum* is inhibited. However, since the use of tannic acid can cause irritation, good ventilation and protective equipment such as goggles and gloves are required when working with tannic acid. Tannic acid itself will not cause stains, but the resulting iron tannate layer can cause stains on wood, but these stains can be removed by oxalic acid (Clemons, 2017).

5.1.3 - Green Approaches to Rust Prevention

Asafoetida extract (ASF) is a green method that can be used to prevent rust as well as having antifungal properties. The details on Asafoetida extract including experiments showing effectiveness of the extract towards preventing corrosion (Patni et al., 2013) and fungi (Amalraj and Gopi, 2016) are discussed in Appendix B.

Aloe vera is another green alternative which can be used to inhibit rust on metal surfaces as well as stop the growth of fungi. Experiments with aloe vera coatings of galvanized iron in acids in *Aloe-Vera: A Green Corrosion Inhibitor* by Shah and Agarwal (2014) show that aloe vera has high inhibition efficiency. This is also shown in a separate experiment by Singh et al. (2016). Furthermore, aloe vera also has antifungal activities, as seen in an experiment on antifungal activity that proved that aloe vera gel and leaf extracts can be used to inhibit the growth of fungi such as *C. albicans* (Shilpa et al., 2020).

However, the use of these natural extracts, such as asafoetida and aloe vera, should still be tested with wood samples first before actual use in the palace structure, and these methods should be used with care because they are natural organic compounds that can be nutrition for fungi if not monitored.

5.1.4 - Replacement of Nails

As mentioned earlier in section 2.3.1, stainless steel nails type 304 and 316 are suitable for rust prevention. Stainless steel nails type 316 have the best resistance property among all grades and seem to be most suitable in corrosive conditions. Although the palace is situated on the seaside, it is not immersed in seawater, thus it does not require the use of nails that are as corrosion resistant as type 316. The palace staff has mentioned that they plan to replace the old iron nails in some parts of the palace with type 304 stainless steel nails as they renovate in the future because the palace staff mentioned that they are more flexible than type 316 and not as brittle.

5.2 - Recommendations on Repairing Concrete Columns

5.2.1 - Repairing Internal Reinforcement Bars

As mentioned in section 2.5 about deterioration of concrete, the signs of rusting in reinforcing steel bars (rebars) are rust stains and cracks on the concrete surface, and repair should take place. If only rust stains appear on concrete, they can be cleaned by methods discussed in section 4.2, but tannic acid should not be used on concrete as stains and damage can occur, leading to the reduction in strength of the concrete structures (The Aberdeen Group, 1981).

However, if the presence of stains can be observed along with cracks, spalling, and deterioration of concrete, reparation is required. For the replacement of internal rebars, coated rebars mentioned in Appendix B are more corrosion resistant against factors such as oxygen, humidity, chloride, and carbon dioxide than plain steel rebars. Stainless steel rebars of types 304 and 316 offer the best performance in corrosion resistance, but are more costly compared to plain steel rebars (T. El-Korchi, personal communication, Feb 23, 2021). Thus, using epoxy-coated rebars should be the most suitable method for the replacement of internal rebars in concrete columns in the palace structure in terms of cost and ability of protection.

5.2.2 - Adding Polymer into Concrete Mix

The addition of polymer into concrete to make polymer cement concrete can be used to repair concrete. For a plain concrete mix, when water evaporates out to form hardened concrete, the final appearance of concrete will have lots of pores on the surface, allowing gases and contaminants to penetrate, leading to the rusting of rebars. Therefore, the addition of polymers into concrete will help reduce the porosity of concrete, lowering water permeability as well as the chloride and carbon dioxide penetration (Diamanti et al., 2013). The properties of common polymers that are used as bonding agents are compared in Appendix E.

5.2.3 - Adding Fly Ash into Concrete Mix

According to a personal interview with professor Tahar El-Korchi from WPI (Feb 23, 2021), the addition of fly ash into concrete to make concrete mixture is another viable method to reduce porosity. It is cheaper than polymers, and commonly mixed into concrete instead of polymers. Additionally, according to *Agents that Attack Concrete* published by The Aberdeen Group (1981), the suitable thickness of the concrete covering the reinforcing steel bars should be equal to or more than 1½ inches. However, for the best protection, the thickness of 3 inches is recommended (T. El-Korchi, personal communication, Feb 23, 2021). Otherwise, if the rebars are positioned too close to the concrete surface, water, gases, or any accelerators can easily penetrate in, leading to rusting of rebars and the deterioration of concrete.

5.2.4 - Concrete Anodes

Concrete anodes (Figure 16) are an alternative way to prevent the rust corrosion in rebars, widely used for corrosion prevention in seawater of surface ships, drilling rigs, or submarine hulls. Concrete anodes, proposed by Thai Marine Protection [TMP] (2020), can be categorized into three different types depending on the surrounding environment, types of reinforcing bars used, and properties of each metal (Appendix F). However, concrete anodes may not be suitable in the case of concrete columns in the palace structure because they would need to be installed in every column containing internal rebars. They are more suitable for the structures with wide and high surface areas, such as construction of bridge decks, floorings, or foundations (T. El-Korchi, personal communication, Feb 23, 2021).

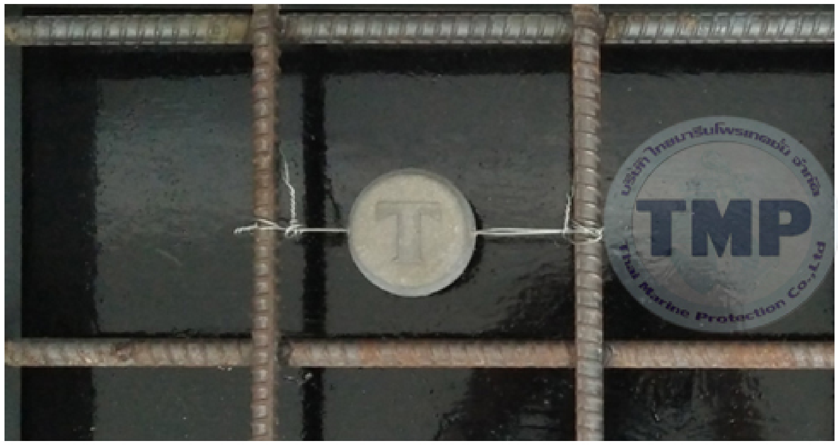


Figure 16. Photo of a concrete anode attached to reinforcement bars. Reprinted from *Corrosion Technologies: Innovation for Corrosion Control* by Thai Marine Protection. (2020).

5.3 - Recommendations on Removal of Fungi

Fungi can be removed by natural products such as baking soda or vinegar, however vinegar can be nutrition for fungi if used in concentrations that are too low. Thus, removing fungi by using chemicals is the best option. If hypochlorite is used, the solution needs to be diluted to 0.37% hypochlorite if removing fungi that reproduce asexually, but if the fungi reproduce sexually, a concentration of 3% hypochlorite is needed (T. Kriangkripipat, personal communication, Jan 27, 2020). Hypochlorite is toxic to the respiratory system, so caution should be taken when using it, and it is recommended for use in well-ventilated areas. Dettol Hygiene Multi-Use Disinfectant is a fungicide that is not as strong as hypochlorite, but it can be used on wood surfaces that are not well-ventilated, such as in closed rooms. However, since hypochlorite molecules are large, these chemicals can only kill parts of the fungi that appear on the wooden surface. The threads of mycelia still remain inside of the wood and cannot be removed without damaging the wood, but its growth can be prevented by drying and applying chemical preservatives to the wood.

5.4 - Recommendations for Drying Wood

Kiln drying requires an oven that controls drying time, temperature, moisture content, and airflow velocity in order to reduce the humidity inside of the wood and make it dry (Soontonbura, 2011). Any wood preservatives used on the wood should be applied before placing the wood in the oven. In the oven, planks of wood are separated by stickers, or pieces of wood that have already been treated and dried, to ensure that all planks of wood will dry at the same time (Smit et al., 2017). Additionally, kiln drying is more suitable than air drying, because there is no control over the temperature and relative humidity in air drying (S. Jarusombuti, personal communication, Feb 24, 2021).

5.5 - Wood Preservatives

5.5.1 - Copper Chrome Boron (CCB)

Copper chrome boron (CCB) is a synthetic wood preservative that was developed as an alternative for CCA. CCB is a chemical salt that dissolves in water, and it can penetrate into the wood structure well. Copper will act as a fungicide and chromium will help other chemicals stay in the wood structure longer. Boron is also a fungicide, but it is not toxic to the environment. However, CCB is recommended for indoor use such as on furniture, since water can cause the boron to leach out of the wood (Sheetz & Fisher, 1993).

There are two common methods of applying wood preservatives are methods that do not use pressure and methods that use pressure (Wongkaluang, n.d.). Non-pressure treatments, such as brushing or spraying the chemical directly onto the wood, may result in the preservative leaching out easily, providing only temporary protection. Methods that require pressure to apply wood preservatives require equipment to pressurize the chemicals into the wood, and are more expensive, but will protect the wood for longer due to the deeper penetration of preservatives. Full cell and empty cell techniques are two methods that require pressure, and since the wood from the palace structure is old, the empty cell technique is sufficient (S. Jarusombuti, personal communication, Feb 24, 2021).

5.5.2 - Micronized Copper Azole (MCA)

Micronized copper azole (MCA) is a wood preservative that is widely used in the United States and Europe and environmentally friendly according to a discussion with Associate Professor Songklod Jarusombuti from Kasetsart University (personal communication, Feb 24, 2021). While copper is used in wood preservatives, the new micronized copper method was created in 2006, where the copper is turned into fine particles that is pressure treated onto the wood along with other additives such as biocides (Sisler et al., 2019). MCA also has special chemistry interactions with the wooden structure, solubilizing quickly, allowing it to be complexed by the molecules in wood, penetrating into the wood structure (Civardi et al., 2016).

However, MCA can be corrosive to metal fasteners, so it is recommended that MCA should be used on wood in areas where old nails were replaced with wooden dowels.

5.6 - Wood Finishes

5.6.1 - Teak Oil

Teak oil is applied onto teak wood to prevent wood from absorbing additional moisture. Teak oil that is sold in stores is different from the natural teak oil present in teak wood because it contains linseed oil or tung oil with other additives to protect teak wood from outside interferences (DesperateSailors, 2021). It is recommended to apply teak oil yearly, but in areas heavily affected by UV radiation such as the palace, it should be applied every 6 months.

5.6.2 - Teak Sealer

Teak sealer is a wood finish used in wooden structures made out of paraffin waxes and various forms of benzenes (Shower Stool Universe, n.d.). The purpose of teak sealer is to retain the oil present in teak wood to prevent it from drying out, as well to protect the wood from UV radiation damage and prevent moisture and any other contaminants from entering the wood.

5.6.3 - Deck Stain

Deck stain is a pigmented wood finish that can give higher UV protection (Deck Stain Help, 2021). Two types of deck stain are present in the market: water-based and oil-based. Oil-based deck stain is recommended because it contains pigments to make the wood look natural. It can also be applied in place of teak oil because it already contains oil. It is recommended to apply deck stain every 1-2 years, but in areas with high UV conditions, it should be reapplied every 6 months.

5.7 - Monitoring System

Monitoring systems of different historical buildings were explored in order to design a monitoring system and monitoring forms for assessing the effectiveness of preservative methods. Systems that use technology such as cameras to monitor an area remotely in Taiwan (Lee et al., 2018) and sensors that constantly record temperature and humidity in Spain (Mesas-Carrascosa et al., 2016) are examples of historical sites that have started to use databases and platforms for monitoring.

However, constant monitoring is expensive and may not be necessary. From the examples of monitoring forms designed available in Appendix C, scheduled time intervals for monitoring are suggested. Inspiration was taken from examples of monitoring forms of historic places in

New Zealand (Walton, 2003) and also from patient monitoring charts used by doctors to design a monitoring form that considers a user-friendly design considering staff from a wide variety of backgrounds.

5.8 - Conclusion

In conclusion, the root causes of rust in both nails and concrete structures, and the growth of fungi in the deterioration of wood were identified from the information obtained from observation, research, and several experts. Many factors and conditions, including high humidity, high salt content from sea salt spray, and the lack of thorough understanding of restoration methods used can all contribute to the corrosion and deterioration of the palace structures. Therefore, in order to alleviate the severity of the problems, our team has suggested some recommendations on rust prevention, fungi removal and prevention, and wood preservation, hoping that this would benefit the Mrigadayavan Palace staff on their restoration project, and also any other historical buildings that have similar structure to the palace. We also designed a monitoring form along with guidelines and manuals to help with the problems of tracking deterioration. Additionally, as the palace now serves as a historical site educating the public on only history and culture, our team decided to provide additional information from a scientific point of view. We provided the palace with the infographics we designed together with some ideas on how to implement the infographics into the actual structure of the palace. This was directed to help in the expansion of public education to cover wider areas of knowledge for the palace museum and learning center.

Annotated Bibliography

The Aberdeen Group. (1981). *Agents that attack concrete*. https://www.concreteconstruction.net/_view-object?id=00000153-9691-dbf3-a177-96b9304d0000

This publication discusses many agents that attack concrete including tannic acid and many other contaminants in the environment. It also suggests a suitable thickness of concrete needed to cover the reinforcing steel to slow down and prevent the deterioration of steel inside the concrete.

Amalraj, A., & Gopi, S. (2017). Biological activities and medicinal properties of asafoetida: A review. *Journal of Traditional and Complementary Medicine*, 7(3), 347–359. https://doi.org/10.1016/j.jtcme.2016.11.004

This paper discusses many effects and activities of asafoetida, including its antimicrobial and antifungal property. It also suggests that the use of asafoetida oil could be viable for all fungi strains and could also strongly inhibit some specific species of fungi.

Armor Protective Packaging. (2019, December 18). *Types of rust*. https://www.armorvci.com/corrosion/types-of-rust/

This website provides the information on the conditions and factors that could lead to rust formation. It also identifies the types of rust and how they form, with clear images to understand. It provides a deeper understanding about the causes of rust, apart from just the environmental cause.

Baker, A. J. (1974). *Degradation of wood by products of metal corrosion*. U.S. Dept. of Agriculture, Forest Service, Forest Products Laboratory. https://www.fpl.fs.fed.us/documnts/fplrp/fplrp229.pdf

This paper provides a diagram and describes in detail the chemical process of how rust occurs and how the corrosion of wood resulting from this process can be accelerated in the presence of soluble chlorides. This helps form a basis for the understanding of the rusting process in order to start finding solutions to prevent the formation of rust.

Barthel, H., Dreyer, M., Gottschalk-Gaudig, T., Litvinov, V., & Nikitina, E. (2002). Fumed silica — Rheological additive for adhesives, resins, and paints. *Macromolecular Symposia*, *187*(1), 573-584. https://doi.org/10.1002/9783527620777.ch117d

This article discusses the use of fumed silica and its applications towards other products such as resins and adhesives.

Bohn, R. (2012, September 27). *What's the difference between 304 and 316 stainless steel*. NEMA Enclosures. https://www.nemaenclosures.com/blog/304-and-316-stainless-steel

This website provides information on the composition of 304 nad 316 stainless steel nails. It also compares these two types of nails, including their advantages and applications.

Brown, M. C. (2002). *Corrosion protection service life of epoxy coated reinforcing steel in Virginia bridge decks* (Dissertation). Virginia Polytechnic Institute and State University. https://vtechworks.lib.vt.edu/bitstream/handle/10919/27690/MCBrownDissertation.pdf

This paper provides a comparison between epoxy-coated steel rebars and bare steel bars without coating from bridge decks construction in Virginia. The corrosion protection service lifetime extension of epoxy-coated steel bars compared to the bare steel is also given. Additionally, laboratory testing to assess the corrosion state of the steel bars exposed to chlorides is also carried out and can be used as supporting information when discussing concrete.

Chadthasing, B. (2004). *Kan ab namya mai* [Bathing wood in chemicals]. Forest and Research Development Office. http://forprod.forest.go.th/forprod/Tips/DETAILS/woodpreserv.htm

This article is written in Thai. It discusses possible causes of wood damage including fungi. It also discusses the different types of fungi and how they damage wood differently. Lastly, it provides the method of using different chemicals in order to prevent fungi.

Cheung, S. N., Lau, T. K., Liu, W. S., Liu, H. K., & Yu, H. K. (n.d.). *Corrosion of iron*. Academia. https://www.academia.edu/11694235/Corrosion_of_Iron

This paper carried out experiments to investigate the optimal conditions to efficiently coat tannic acid onto a rusted surface. Some of the investigations include duration of coating, concentration of tannic acid, and temperature. It also discusses the mechanism of how tannic acid is converted into iron tannate to protect the iron nails from further rusting.

Civardi, C., Van den Bulcke, J., Schubert, M., Michel, E., Butron, M. I., Boone, M. N., Dierick, M., Van Acker, J., Wick, P., & Schwarze, F. W. M. R. (2016). Penetration and effectiveness of micronized copper in refractory wood species. *PLOS ONE*, *11*(9), e0163124. https://doi.org/10.1371/journal.pone.0163124

This study illustrates how MCA works in the wooden structure. Furthermore, it is a study on how the penetration of this wood preservative on types of wood.

Clark, M. A., Douglas, M., & Choi, J. (2018, March 28). Fungi. In *Biology 2e*. OpenStax. https://openstax.org/books/biology-2e/pages/24-1-characteristics-of-fungi

This chapter of the *Biology 2e* book provides information about fungi, including information on its reproductive cycles and classification of fungi.

Clemons, C. (2017, March 29). *Removal of stains and tannins in oak*. From the Oak Tree. https://fromtheoaktree.co.uk/blogs/news/removal-of-stains-and-tannins-in-oak

This website provides information on how to remove iron tannate stains on wood by using oxalic acid. The ratio of the solution used to remove the stains are also given.

Cohn, N., Cotto, N., Janprasert, P., Kunmas, C., Mohammadali, R., Raque, M., Seely, M., & Vjirsangpyroj, P. (2020). *Assessing the impact of human activity on the groundwater at the Mrigadayavan Palace in Cha Am, Thailand*.

http://bsac.chemcu.org/issp-2020-assessing-the-impact-of-human-activity-on-the-ground water-at-the-mrigadayavan-palace-in-cha-am-thailand/

This paper from the previous year's IQP-ISSP project dealing with groundwater in the palace provides an understanding of what has previously been done at the palace and what recommendations were previously given to the palace staff.

Construction Fasteners & Tools. (2020, September 2). *Tool maintenance: Cleaning, rust prevention & rust removal*. https://cf-t.com/blog/tool-maintenance-rust-removal

This website provides information on how to remove rust from metal surfaces. Many methods are given along with steps which are easy to understand and follow.

Deck Stain Help. (2021, January 24). *What's the difference between a deck sealer and a deck stain?* https://www.deckstainhelp.com/whats-the-difference-between-a-deck-sealer-and-a-deck-stain/

This article highlights how deck sealers differ from a deck stain. In addition explaining how deck stains operate to protect wood.

Department of Public Works and Town & Country Planning. (2008). *Matrathan patibat nai kan som saem konkrit* [Standard practices in repairing concrete]. http://subsites.dpt.go.th/edocument/images/pdf/sd_work/MRT05.pdf

This is a document published by the Department of Public Works and Town & Country Planning on the restoration project of concrete construction in Thai. They discuss the materials used in the reparation of concrete structure including the reparation on reinforcing steel bars and the concrete surface.

DesperateSailors. (2021, January 19). *Teak oil vs teak sealer - Which is better for a boat?* https://www.desperatesailors.com/teak-oil-vs-teak-sealer/

This article provides relevant information on teak oil and teak sealers. It gives the components of teak oil and the advantages and disadvantages of using teak sealer and teak oil.

Diamanti, M. V., Brenna, A., Bolzoni, F. M., Berra, M., Pastore, T., & Ormellese, M. (2013). Effect of polymer modified cementitious coatings on water and chloride permeability in concrete. *Construction and Building Materials*, *49*, 720-728. https://doi.org/10.1016/j.conbuildmat.2013.08.050

This paper discusses the effect of polymer modified cementitious coatings as a physical barrier against water and chloride permeation in the concrete. It states that the application of these coatings can reduce the rate of chloride and water diffusion in concrete.

Drury, P., & McPherson, A. (2008). *Conservation principles, policies and guidance*. English Heritage. https://historicengland.org.uk/images-books/publications/conservation-principles-sustainable-management-historic-environment/

This publication provides information on the understanding of conservation principles and heritage values on the historical environment.

Duncan, C. G., & Deverall, F. J. (1964). Degradation of wood preservatives by fungi. *Applied Microbiology*, *12*(1), 57-62. https://europepmc.org/article/med/16349644

This paper discusses the effect of fungi on wood preservatives. It provides an understanding on how fungi can break down wood preservatives, making them less effective over time.

Farmer, R. H. (1967). *Chemistry in the utilization of wood* (1st ed.). Pergamon Press. https://doi.org/10.1016/C2013-0-02046-4

This book gives information on structural components of wood as well as how the chemical nature of wood influences its properties and applications. The corrosion of metals associated with wood is also discussed in this paper. There is also a chapter which discusses the chemical aspects of wood attack by fungi and insects. This provides us with a better understanding of how all of these problems of corrosion and fungi are related.

Hilti Corporation. (2015). *Corrosion handbook* [PDF]. https://www.hilti.com.ar/content/dam/documents/pdf/temp/Corrosion-Handbook_global_W4412_en.pdf

This handbook provides useful information about corrosion. It provides basic information on corrosion and protection solutions with many diagrams and experimental results to support its claims.

Komchadluek. (2019, July 12). *Nayok widsawakon phoei sam sahet phanpun biti'es ruang* [The president of TSEA reveals three reasons for the fall of cement sheets from the BTS]. https://www.komchadluek.net/news/breaking-news/379382

This news article, in Thai, provides a case study on the deterioration of concrete construction of the BTS, a mass transit system in Bangkok, Thailand. The causes of the cracking and spalling of concrete are also stated by the engineers in this article.

Larsen, K. E., & Marstein, N. (2000). *Conservation of historic timber structures: An ecological approach.* https://core.ac.uk/download/pdf/154668354.pdf

This book discusses various ways on how wood preservation was performed along with the various factors to make it viable. Furthermore, it provides examples on how wood preservation was performed in the past.

Lee, Y.-L., Lu, M.-J., & Shiau, Y.-C. (2018). The development of a digital management system for historic buildings in Taiwan. *Arts*, *7*(3), 34. https://doi.org/10.3390/arts7030034

This paper discusses the use of a digital management system to help perform preservation and management-related work in historical sites in Taiwan. It explains concepts on preservation and digital system structures with an example of a building that has implemented the system.

Little, B., & Ray, R. (1999, October). *Fungal influenced corrosion of metals in humid environments*. https://apps.dtic.mil/dtic/tr/fulltext/u2/a371921.pdf

This report discusses the mechanism of the influence of fungi on the corrosion of metals in humid environments. It also provides us the relative humidities at which the fungi can thrive and produce acidic by-products, which could further cause the metals and wood to corrode. We could use this report as supporting information on how fungi could play an important role in metal corrosion.

Loferski, J. R. (1999). Technologies for wood preservation in historic preservation. *Archives and Museum Informatics*, *13*(3/4), 273–290. https://doi.org/10.1023/a:1012468326445

This paper provides insight on how biological and non-biological factors deteriorate wood and different methods for wood preservation. It provides suggestions and examples on how to take care of wood and how to monitor it after preservation.

Logan, J. (1989). *Tannic acid coating for rusted iron artifacts, formerly published under the title Tannic Acid Treatment – Canadian Conservation Institute (CCI) notes 9/5 - Canada.ca*. Government of Canada. https://www.canada.ca/en/conservation-institute/services/conservation-preservation-publications/canadian-conservation-institute-notes/tannic-acid-rusted-iron-artifacts.html

This article combines information from different journals and articles together, which makes it complete and easy to understand. It presents information about tannic acid and how it can be used to treat rust on metal. It also states the effect of tannic acid and how to take care of the metal after it has been treated with tannic acid. This is a useful source to examine how tannic acid works since the palace is currently using tannic acid to prolong rust in areas awaiting restoration.

Loughborough, W. K. (1936). Seasoning with chemicals. *The Timberman*, *37*(11), 16-17, 30, 32. https://www.fpl.fs.fed.us/documnts/pdf1936/lough36b.pdf

This article provides information about wood drying methods by submerging the wood into a chemical solution which will help hasten the drying process of wood due to the differences of vapor pressure of the solution.

MakeWoodGood. (2020, December 22). *Nail rot in timber on a strip built (or strip planked) boat. How to cure it*. https://www.makewoodgood.co.uk/curing-nail-rot-timber-strip-built-or-strip-planked-boat/

This article provides information about how to cure the nail rot in timber and how the curing process can happen. This article discusses nail rot in timber on a strip built boat which can be related to the project, as corrosion occurs in a similarly humid environment. The curing of nail rot in this situation may apply to nail and wood rot for the seaside palace.

Mesas-Carrascosa, F., Verdú Santano, D., Meroño de Larriva, J., Ortíz Cordero, R., Hidalgo Fernández, R., & García-Ferrer, A. (2016). Monitoring heritage buildings with open source hardware sensors: A case study of the mosque-cathedral of Córdoba. *Sensors*, *16*(10), 1620. https://doi.org/10.3390/s16101620

This paper discusses the use of sensors that monitor temperature and relative humidity inside of a cultural heritage in Spain. The sensors constantly monitored those two factors to map areas of fluctuation in conditions within the building.

Miranda, I., Sousa, V., & Pereira, H. (2011). Wood properties of teak (*Tectona grandis*) from a mature unmanaged stand in East Timor. *Journal of Wood Science*, *57*(3), 171–178. https://doi.org/10.1007/s10086-010-1164-8

This paper discusses the properties of teak wood, such as its mechanical properties, hardness, and chemical composition. This provides a basic introduction to understanding teak wood, which is used in the palace's structure.

Mrigadayavan Palace. (n.d.). http://www.mrigadayavan.or.th/landing/english/eng_home.html

This website is our sponsor's official website. It contains valuable background information to understand the palace better. The website also includes a page about its history and some information on its past restoration attempts. Another page of importance describes and explains the architecture of the palace, its design, and its layout. It also describes the attempts of previous restorations. This site provides the team with a better understanding of the palace's architecture.

Nasvik, J. (2001). *Understanding polymers in concrete*. Hanley-Wood. https://www.concreteconstruction.net/_view-object?id=00000153-8bc6-dbf3-a177-9fff56300000

This publication provides the understanding of polymers in concrete. It provides common types of polymers that are used in the construction of concrete along with a comparison table between polymers. Characteristics and properties of each type of polymer are also given.

National Physical Laboratory. (n.d.). *Guides to practice in corrosion control: Corrosion of metals by wood*. http://resource.npl.co.uk/docs/science_technology/materials/life_management_of_materials/publications/online_guides/pdf/corrosion_of_metals_by_wood.pdf

This document gives a brief overview of different substances that can corrode wood such as fungi and metals, and some suggested treatments for the wood. This provides some guidance to preservation options that the team can explore further.

Norton, C. (2019, July 23). *How to dry wet wood really fast?* Stoney Creek Woodworks. http://www.stoneycreekwoodworks.com/how-to-dry-wet-wood-fast/

This article provides several methods of drying wet wood such as spacing out wood in ventilated spots or using heat treatment. Wood has to be dried to reduce the chances of fungi from reappearing.

Ocampo, L. M., Margarit, I. C. P., Mattos, O. R., Córdoba-de-Torresi, S. I., & Fragata, F. L. (2004). Performance of rust converter based in phosphoric and tannic acids. *Corrosion Science*, *46*(6), 1515–1525. https://doi.org/10.1016/j.corsci.2003.09.021

This paper provides information on the performance of rust converters based on phosphoric and tannic acids in different corrosion degrees and salt contaminations. It displays results including X-ray, Infrared, and Raman spectroscopy analyses to support which chemicals could be useful to inhibit corrosion.

Painter, S. (n.d.). *How to remove old and new rust stains from concrete*. LoveToKnow. https://cleaning.lovetoknow.com/outdoor-cleaning/how-remove-old-new-rust-stains-from-concrete

This article provides many ways to remove rust stains from a concrete surface, including steps, which are easy to follow. This could be useful if the concrete columns display rust stains, but are not cracked or deteriorated.

Patni, N., Agarwal, S., & Shah, P. (2013). Greener approach towards corrosion inhibition. *Chinese Journal of Engineering*, *2013*, 1–10. https://doi.org/10.1155/2013/784186

This paper provides green approaches towards corrosion inhibition, which can be used in place of toxic chemicals to treat rust. Examples of green extracts derived from plant origin include tannins, tobacco, black pepper, and grape pomace. All of these green corrosion inhibitors were tested with different types of metals in different mediums including alkaline and acidic conditions, and different results were obtained.

Peter (2019, April 18). *Rust prevention 101: The complete guide*. Ocean Footprint. https://oceanfootprint.co.uk/rust-prevention-101-nyalic-the-guide/

This website provides some interesting facts and statistics about rust and corrosion. It also provides simple methods to remove rust from nails.

Pettersen, R. C. (1984). The chemical composition of wood. *Advances in Chemistry*, *207*, 57–126. https://doi.org/10.1021/ba-1984-0207.ch002

This paper provides an understanding of the composition of wood: cellulose, hemicellulose, and lignin. This leads to insight on which chemicals or species of fungi can interact with and decompose wood.

Perfect Concrete Care. (2020, October 8). *How to remove rust stains from concrete*. https://perfectconcretecare.com.au/blog/how-to-remove-rust-stains-from-concrete/

This website suggests many ways to remove the rust stains off the concrete surfaces, ranging from minor stains to major stains. Some examples include vinegar, lemon juice and oxalic acid.

Portland Cement Association. (n.d.). *Corrosion of embedded metals.* https://www.cement.org/learn/concrete-technology/durability/corrosion-of-embedded-materials

This article provides information about the corrosion of reinforcing steel bars inside the concrete structure. It provides chemical equations for the corrosion process that occurs inside the concrete as well as clear images, which are easy to follow and understand.

Rapczynski, C. (2018, August 6). *Rust proof nails to use for outdoor jobs*. Sleeping Dog Properties. https://www.sleepingdogproperties.com/perspectives/rust-proof-nails-for-outdoors/

This article provides a simple guide to the different grades of stainless steel nails that are available. The descriptions of the mails can help assist in comparing and selecting the best type of nail to use. This article also suggests causes of wood rust and some catalysts which accelerate the rusting process.

Sakunjaroenpornchai, P. (2017). *The restoration management of Mrigadayavan Palace* (Master's dissertation). Chulalongkorn University. http://cuir.car.chula.ac.th/handle/123456789/60672

This thesis, written in Thai, from the Faculty of Architecture, Chulalongkorn University, discusses the management of resources, people, and the process of different restoration projects that the palace has undergone in the past. This would benefit the team in understanding more of the social aspect in the restoration project and how different people are involved.

Satittawilwong, N. (2012, August 19). *Prawat baan ruenthai* [The history of Thai traditional houses]. Google Sites. https://sites.google.com/site/testngngtest/prawati-ban-reuxnthiy

This website provides information on the history of Thai traditional houses since the reign of King Rama I to King Rama VIII. It also states that the combination between wood and concrete structure of Thai architecture began in the reign of King Rama IV.

Schmidt, O. (2006). *Wood and tree fungi: Biology, damage, protection, and use* (1st ed.). Springer. https://doi.org/10.1007/3-540-32139-X

This book provides a good understanding about wood and how it can be damaged by different agents such as fungi and bacteria. Information about fungal growth and spreading are also provided in detail with images. This book helps us to learn more about the relationship between wood and fungi, and this can also be used as supporting information in our report as many analyses have been carried out, and is considered to be a very reliable source.

Shah, P., & Agarwal, S. (2014). Aloe-vera: A green corrosion inhibitor. *International Journal for Research in Applied Science and Engineering*, *2*(5), 14-17. https://www.researchgate.net/publication/271830023_Aloe-Vera_A_Green_Corrosion_Inhibitor

This paper provides information on aloe vera as a green corrosion inhibitor. The experiment on the effect of aloe vera as a green inhibitor on the iron nails in different solution mediums is carried out.

Shaker, M. R., & Reddy, R. R. (2009, February). *Re-alkalization of carbonated reinforced cement concrete members*. NBM Media Pvt. https://www.nbmcw.com/tech-articles/concrete/934-re-alkalization-of-carbonated-reinforced-cement-concrete-members.html

This website provides an explanation for the reduction of alkalinity inside the concrete construction, including the carbonation reaction and carbonic acid formation. These reactions can lead to the corrosion of reinforcing steel bars.

Sheetz, R., & Fisher, C. (1993). *Exterior woodwork number 4: Protecting woodwork against decay using borate preservatives*. https://www.nps.gov/tps/how-to-preserve/tech-notes/Tech-Notes-Exterior04.pdf

This paper provides a case study on how wooden structures are protected using borates. It provides an in-depth reasoning and methodology to follow.

Shilpa, M., Shetty, A. V., Bhat, V., Reddy, M. S. R., & Punde, P. (2020). Antifungal activity of aloe vera leaf and gel extracts against *Candida albicans*: An *in vitro* study. *World Journal of Dentistry*, *11*(1), 36–40. https://doi.org/10.5005/jp-journals-10015-1701

This paper discusses an experiment on antifungal activity of aloe vera leaf and gel extracts against *Candida albicans* fungi species. The antifungal activity is assessed by different methods and is proven by microscopic images. There are also some graphs that illustrate the percentage of inhibition against concentration of aloe vera which can be used as supporting information.

Shower Stool Universe. (n.d.). *Teak sealer furniture protection guide: 7 best picks on the market*. https://teakshowerstools.net/best-teak-sealer/

This article provides in depth information on teak sealers, primarily on the main components of teak sealer and product suggestions.

Shupe, T. F., Lebow, S. T., & Ring, D. R. (2008). *Causes and control of wood decay, degradation & stain*. Louisiana State University Agricultural Center, Louisiana Cooperative Extension Service. https://www.srs.fs.usda.gov/pubs/35536

This book provides detailed information about different types of fungi that can destroy and stain wood. It also gives suggestions about which wood preservatives are recommended for protection from different types of fungi. Additionally, it also gives information on different types of stains that can appear on wood as well as different types of insects and pests that might contribute to the deterioration of wood.

Singh, A. K., Mohapatra, S., & Pani, B. (2016). Corrosion inhibition effect of aloe vera gel: Gravimetric and electrochemical study. *Journal of Industrial and Engineering Chemistry*, *33*, 288–297. https://doi.org/10.1016/j.jiec.2015.10.014

This paper provides information on the corrosion inhibition effect of aloe vera gel when tested with mild steel in HCl medium. The optimum concentration of aloe vera gel giving high inhibition efficiency and low corrosion rate is also given.

Sisler, J. D., Mandler, W. K., Shaffer, J., Lee, T., McKinney, W. G., Battelli, L. A., Orandle, M. S., Thomas, T. A., Castranova, V. C., Qi, C., Porter, D. W., Andrew, M. E., Fedan, J. S., Mercer, R. R., & Qian, Y. (2019). Toxicological assessment of dust from sanding micronized copper-treated lumber in vivo. *Journal of Hazardous Materials*, *373*, 630–639. https://doi.org/10.1016/j.jhazmat.2019.02.068

This paper introduces a brief history of MCA, as well the technical details of the wood preservative.

Smit, G. J. F., du Plessis, J. P., & du Plessis, J. P. (2007). Modelling of airflow through a stack in a timber-drying kiln. *Applied Mathematical Modelling*, *31*(2), 270–282. https://doi.org/10.1016/j.apm.2005.11.003

This scientific article is about modeling the airflow for wood drying methods such as kiln drying and air drying.

Soontonbura, W. (2011). *Kan sang tarang ob mai* [Making wood drying chamber]. Forest and Research Development Office. http://forprod.forest.go.th/forprod/wood_industries/pdf/%E0%B8%81%E0%B8%B2%E0

%B8%A3%E0%B8%AA%E0%B8%A3%E0%B9%89%E0%B8%B2%E0%B8%87%E0%B8%95%E0%B8%B2%E0%B8%A3%E0%B8%B2%E0%B8%87%E0%B8%AD%E0%B8%9A%E0%B9%84%E0%B8%A1%E0%B9%89%E0%B9%80%E0%B8%9C%E0%B8%A2%E0%B9%81%E0%B8%9E%E0%B8%A3%E0%B9%88.pdf

This paper is written in Thai and is mainly about kiln drying wood, which is the most common wood drying method in order to prevent fungi from returning.

Thai Marine Protection. (2020). *Corrosion technologies: Innovation for corrosion control*. http://www.thaimp.co.th/faq/FAQ%20Concrete%20Anode%20Th.html#03

This website, in Thai, provides information on the reparation of concrete construction to prevent the corrosion of rebars by using concrete anode. It provides details on the mechanism of the protection by a concrete anode. It also provides a comparison between normal reparation method and the reparation by using concrete anode.

Thévenon, M.-F., Tondi, G., & Pizzi, A. (2010). Friendly wood preservative system based on polymerized tannin resin-boric acid for outdoor applications. *Ciencia y Tecnología*, *12*(3), 253–257. https://doi.org/10.4067/s0718-221x2010000300009

This paper suggests useful information on environmentally friendly wood preservative systems that could be used for outdoor applications. It also shows the experimental procedures and methodology on how the results are obtained.

UKEssays. (2018). *Vinegar as a rust remover: Experiment*. https://www.ukessays.com/essays/biology/potential-of-vinegar-as-rust-stain-remover-biology-essay.php?vref=1

This essay provides details of using vinegar as a rust stain remover. It also states the precautions of what should be done after the rust is washed off the nails by vinegar. There is also an experiment carried out to investigate the percentage of vinegar whether increasing its percentage would account for higher removal efficiency or not.

Walton, A. (2003). *Methods for monitoring the condition of historic places*. Department of Conservation. https://www.doc.govt.nz/documents/science-and-technical/docts27.pdf

This report explains how monitoring is done at different historical sites in New Zealand. There are examples of monitoring forms used at these places.

Wilder, C. (n.d.). *The disadvantages of fly ash in concrete*. Hunker. https://www.hunker.com/13425141/the-disadvantages-of-fly-ash-in-concrete

This website discusses the disadvantages and limitations of mixing fly ash into concrete.

Wongkaluang, C. (n.d.). *Kan pong kan rak sa nuea mai* [The protection of wood]. Forest and Research Development Office. http://bit.do/fNEZe

This paper, written in Thai, is from the Forest Research and Development Office, and it contains details about the usage of wood such as wood destroying agents, the natural durability of wood, and wood preservatives.

Yeomans, S. R. (2018). *Galvanized reinforcement: Recent developments and new opportunities*. https://www.researchgate.net/publication/328303325_Galvanized_Reinforcement_Recent_Developments_and_New_Opportunities

This paper provides information on the service life of different types of reinforcement bars inside concrete, including the comparison for epoxy-coated rebars, zinc-coated rebars, and stainless steel rebars.

Zelinka, S. L., & Rammer, D. R. (2005). Review of test methods used to determine the corrosion rate of metals in contact with treated wood. *Frame Building News*, 38-46.

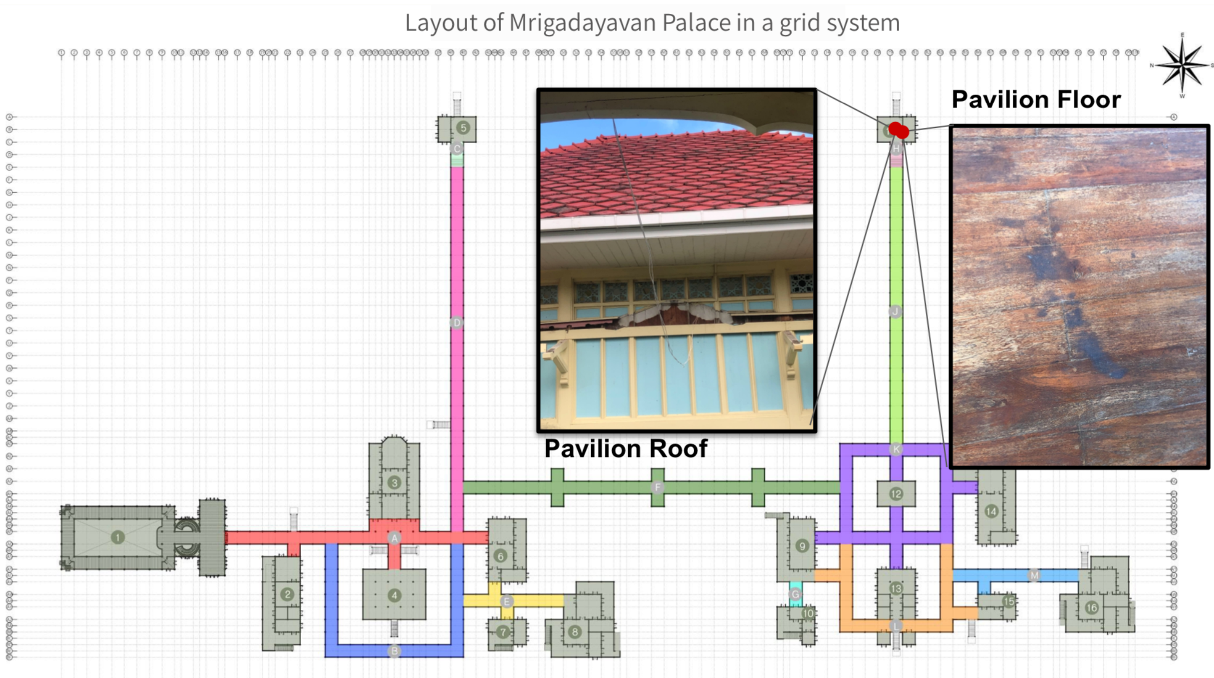
This paper discusses different methods to test the corrosion rate of metal fasteners in wood. These test methods can be used to monitor corrosion and rust in wood, which can form a basis for corrosion monitoring plans for the palace.

Zhu, C., Lei, M., Andargie, M., Zeng, J., & Li, J. (2019). Antifungal activity and mechanism of action of tannic acid against *Penicillium digitatum*. *Physiological and Molecular Plant Pathology*, *107*, 46–50. https://doi.org/10.1016/j.pmpp.2019.04.009

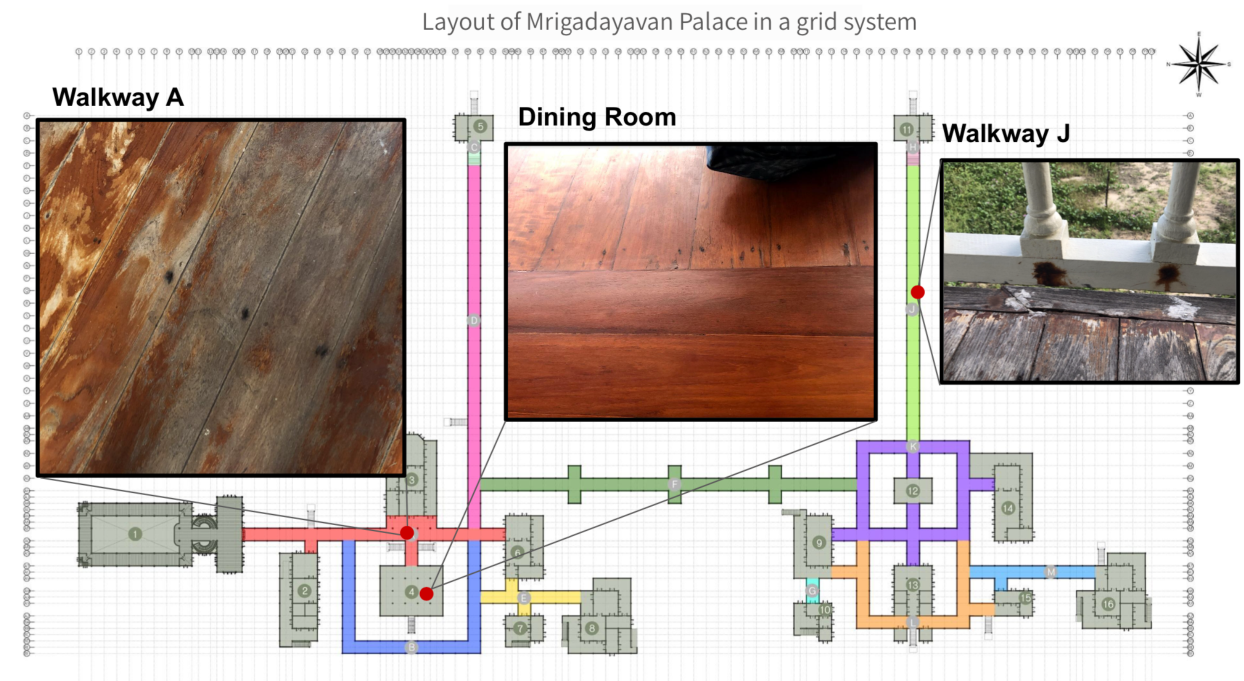
This paper provides information on the antifungal activity of tannic acid. The mechanism of how tannic acid is used against fungi is also stated. The experiment is carried out by testing tannic acid with the fungi that grow on citrus fruits and observed the antifungal activity of tannic acid.

Appendix A - Mapping of Areas of Deterioration in the Mrigadayavan Palace

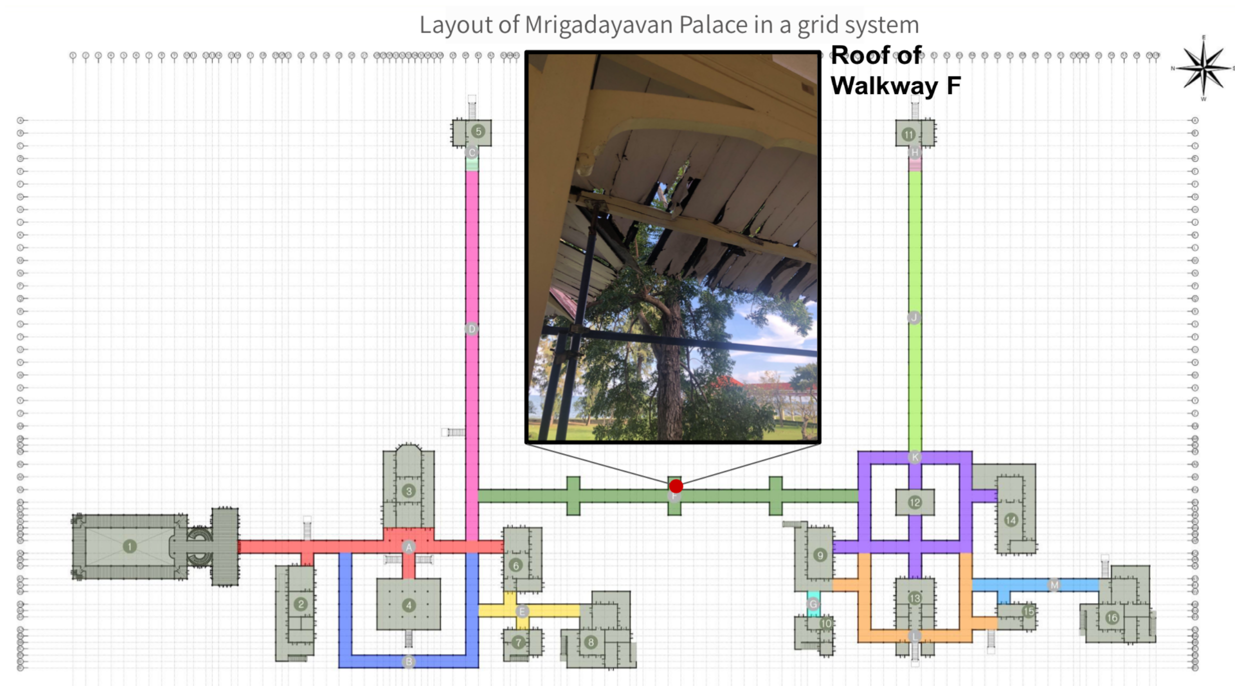
In the provided diagram, structures closer to the ocean are near the top, and structures more inland are found near the bottom.



The pavilions are the closest structures to the ocean, right by the seaside, and structural damage to the roof of one of the pavilions can be seen. Black stains of fungi can also be seen to cover a large area of the pavilion floor.



The rust from the head of nails on walkway J have spread into a wide radius onto the wood, when compared to rust that have barely spread from the head of nails in more inland structures such as the dining room and walkway A in front of the dining room.



An example of deterioration of wood planks resulting from moisture from nearby trees on the roof of walkway J.

Appendix B - Table Comparing Restorative and Preventive Methods

Method	Description	Pros	Cons	Cost	Toxicity	Sources
Methods to Remove Rust						
Vinegar or vinegar + lemon juice	Vinegar is a dilute solution of acetic acid. For rust that is tougher to remove, use equal parts vinegar and lemon juice.	Natural, cheap, and can be easily found in the market	Can cause iron to rust again if not cleaned thoroughly	- Vinegar: around 60-70 baht/5 liters - Lemon juice: around 75 baht/3 liters	Vinegar may cause skin and eyes irritation	(Painter, n.d.) (Peter, 2019) (UKEssays, 2018)
Salt and lime	Sprinkle salt and squeeze lime onto rust, leave for a few hours, and scrub clean.	Natural, cheap, and can be easily found in the market	Can cause iron to rust again if not cleaned thoroughly	- Salt: around 10 baht/1 kg - Lime: around 5-6 baht each	Non-toxic	(Peter, 2019)
Potato and dish soap	Oxalic acid in the potato can be used to remove rust.	Cheap and can be easily found in the market	N/A	- Potato: around 30-40 baht/1 kg - Dish soap: around 20-30 baht/550 mL	Non-toxic (Dish soap may cause eyes and skin irritation)	(Peter, 2019)
Molasses and water	Used in a ratio of 1:10 to remove rust.	Cheap and can be easily found in the market	Can be nutrition for fungi if not cleaned thoroughly	Molasses: around 120 baht/5 liters	Non-toxic	(Peter, 2019)

Method	Description	Pros	Cons	Cost	Toxicity	Sources
Oxalic acid	Can be used to remove rust from metal or concrete surfaces as well as iron stains on wood. Should be used with caution when used on wood embedded with nails that are coated with tannic acid, since oxalic acid can also remove the rust and protective layer of iron tannate on the nails.	Can be used to remove rust stains on concrete	Stain can return if rust is not removed thoroughly	Oxalic acid powder: 50 baht/100 g	Can irritate respiratory tract, eyes and skin	(Construction Fasteners & Tools, 2020) (Perfect Concrete Care, 2020)
Methods to Prevent Rust						
Tannic acid	Tannic acid is a complex organic acid extract commonly found in plants. It can be used to apply on an already rusted surface to convert rust into a protective layer of blue-black iron tannate to protect the iron underneath from further rusting.	- Prolongs the rusted surface by inhibiting the spreading of rust - Has antifungal properties	- May need to monitor regularly as its service life cannot be specified (depends on environmental conditions) - Iron tannate layer may cause stains on wood	Tannic acid powder: 400 baht/50 g	Can irritate respiratory tract, eyes and skin	(Clemons, 2017) (Logan, 1989) (Chueng et al., n.d.) (Zhu et al., 2019)

Method	Description	Pros	Cons	Cost	Toxicity	Sources
Asafoetida extract	Substance extracted from Asafoetida plants and can be coated on cleaned nails or metal to protect them from rust.	- Natural extract, environment-ally friendly - Has antifungal properties	- Strong, pungent, unpleasant smell - Regular monitoring required as service life is not specified	- Gum resin: 400-500 baht per 1kg - Asafoetida powder: around 600 baht per 1kg	Non-toxic (but may cause irritation to skin and eye)	(Amalraj & Gopi, 2016) (Patni et al., 2013)
Aloe vera	Aloe vera gel extracted from aloe vera leaves can be applied on cleaned nails or metal to protect them from rust.	- Natural extract, environment-ally friendly, and cheap - Has antifungal properties	Regular monitoring required as service life is not specified	Around 100 baht per 500 mL (or can be extracted from aloe vera leaves)	Non-toxic (but may be allergic to some people, causing burning or itching of skin)	(Shah & Agarwal, 2014) (Shilpa et al., 2020) (Singh et al., 2016)
Replacement with stainless steel nails	Stronger than iron nails, and viable grades are type 304 and type 316 with a service life around 50 years.	High corrosion resistance	Expensive compared to other types of nails	- Type 304 cost around 1600 baht per 1 kg - Type 316 cost around 2500 baht per 1 kg	N/A	(Bohn, 2012) (Rapczynski, 2018)

Method	Description	Pros	Cons	Cost	Toxicity	Sources
Methods to Repair Concrete Columns						
Replacement of internal reinforcement bars (rebars)	If the internal rebars are too rusted to be repaired, they should be replaced with new rebars. - Epoxy-coated rebars (Service life: around 55 years) - Zinc-coated rebars (Service life: around 100 years) - Stainless steel rebars (Service life: 100+ years) Service life given is an approximate number.	Offers more corrosion resistance than plain steel rebars	Require regular monitoring and regular reparation if needed	Epoxy-coated rebars (cheapest) < zinc-coated rebars < Stainless steel rebars (most expensive)	N/A	(Department of Public Works and Town & Country Planning, 2008) (Yeomans, 2018)
Mixing polymer into concrete	Polymers help reduce the porosity of concrete surfaces, lowering the chance of water, chlorides, carbon dioxide, and oxygen penetration.	Help extend the service life of concrete columns	More expensive than fly ash	Depends on the type of polymer used. For example, acrylic costs around 600 baht per 1 bucket (20kg).	Most polymers such as Acrylic are non-toxic	(Department of Public Works and Town & Country Planning, 2008) (Diamanti et al., 2013)

Method	Description	Pros	Cons	Cost	Toxicity	Sources
Mixing fly ash into concrete	Fly ash is the by-product from coal burning in electric power plants. It is mixed with concrete to help reduce the porosity of concrete, similar to polymers.	- Cheaper than polymers, but offers similar protection - Help extend the service life of concrete columns	Longer setting time of concrete required (Lower temperature also lengthens the setting time)	Fly ash costs around 1000 baht per ton	Fly ash may cause skin, eyes and respiratory irritation	(T. El-Korchi, personal communication, Feb 23, 2021), (Wilder, n.d.)
Concrete anode	A concrete anode is made from a different metal than internal rebars, and is attached to the rebars, sacrificing itself to corrosion before the rebars.	- Cheaper than normal method of reparation, as it requires less steps - No need to modify reinforcing rebars, just install the concrete anode	Complicated in terms of installation, calculation of the area, and how many anodes are needed (May need to hire an expert or specialist to do so)	Around 1300-2000 baht per piece, depending on type of anode, size, and weight	N/A	(Thai Marine Protection, 2020)

Method	Description	Pros	Cons	Cost	Toxicity	Sources
Methods to Remove Fungi						
Hypochlorite	Hypochlorite is present in many household cleaning products such as bleach. Solutions containing hypochlorite can be used to remove fungi if prepared in the right concentration.	The most efficient way to remove fungi, cheap, and can be easily found in the market	- Toxic to respiratory system - May bleach the color of wood	Haiter (contains hypochlorite): 135 baht/5000 mL	Can release gases that are toxic to the respiratory system	(T. Kriangkripipat, personal communication, Jan 27, 2021)
Dettol Hygiene Multi-Use Disinfectant	An alternative of hypochlorite that can also be used to remove fungi.	Does not release as much toxic gas as hypochlorite	Not as powerful as hypochlorite	Dettol: 314 baht/500 mL	Chloroxylenol in Dettol has low toxicity in humans, but is highly toxic to fish or aquatic invertebrates.	(T. Kriangkripipat, personal communication, Jan 27, 2021)

Method	Description	Pros	Cons	Cost	Toxicity	Sources
Methods to Dry Wood						
Kiln drying	A method used to dry wood by heating the wood in a controlled oven at specified conditions, such as temperature and relative humidity.	There is control of air flow rate, temperature and humidity in the oven	- Expensive - Need to transport wood - Suitable conditions in the oven depend on calculations by experts or a reliable table	Depends on the size, type, and amount of wood to be dried.	N/A	(S. Jarusombuti, personal communication, Feb 24, 2021) (Soontonbura, 2011)
Air drying	Alternative of kiln drying, where wood is simply left in the outside environment to dry.	- Cheaper than kiln drying - No need for equipment	Drying time depends on the weather, which may lead to fungal growth in areas with high humidity.	Essentially free	N/A	(S. Jarusombuti, personal communication, Feb 24, 2021)

Method	Description	Pros	Cons	Cost	Toxicity	Sources
Wood Preservatives						
Copper chrome boron (CCB)	Developed as an alternative of CCA, which is banned because it contains arsenic. Boron in CCB is a more environmentally friendly alternative, but suitable for indoor use.	Copper is an antifungal agent	Boron can leach out of the wood when in contact with water	CCB from Aadinath Chemical Industries: 70 Baht/1 kg	(No MSDS found for CCB, however the NFPA rating of boron, the main component in CCB is 1 in Health Hazard)	(S. Jarusombuti, Feb 24, 2021) (Wongkaluang, n.d.)
Micronized copper azole (MCA)	Micronized copper azole contains small copper particles (ranging from 1 nm-250 µm) and is an environmentally friendly wood preservative widely used in the United States and Europe.	Contains small particles that are able to penetrate deeper into wood	May cause corrosion in metal fasteners	Depends on the size, type, and amount of wood to be pressurized.	NFPA Health Hazard - 1	(Sisler et al., 2019) (Civardi et al., 2016)

Method	Description	Pros	Cons	Cost	Toxicity	Sources
Wood Finishes						
Teak oil	Teak oil is applied in many coats onto wood to protect wood from absorbing moisture. It is a product made specifically for use with teak wood. It doesn't contain natural teak oil, but it is instead made from linseed oil or tung oil and other supplements.	- Restores the appearance of wood - Protects wood from absorbance of moisture	Frequent application needed	TOA: 715 Baht / 3.5 L	Can cause redness and irritation to skin if in contact	(DesperateSailors, 2021)
Teak sealer	Teak sealer is a chemical product that is applied to prevent the oil in the wood from evaporating out and provides protection from outside interference.	- Provides a higher level of protection	Need to remove old sealer before applying a new coat	JustTeak: 2040 Baht / 1 L	NFPA Health Hazard - 2	(DesperateSailors, 2021) (Shower Stool Universe, n.d.)
Deck stain	A wood finish that comes in many colors and can provide the wood with a natural look. Can be water-based or oil-based.	- Ease of application - Provides a natural look to wood	More maintenance required	Beger: 1160 Baht / 1 GL (3.8 L)	Can cause mild irritation when in contact	(Deck Stain Help, 2021)

Appendix C - Monitoring Forms

BASELINE MONITORING FORM
เอกสารการเฝ้าสังเกตเบื้องต้น

* Use this form for the first evaluation, for following evaluations please refer to Monitoring Form
*** ใช้ในการประเมินครั้งแรก ในการประเมินครั้งต่อไปกรุณาใช้ เอกสารการเฝ้าสังเกต**

Section 1 – Background Information	**ส่วนที่ 1 – ข้อมูลพื้นฐาน**
Date (dd/mm/yyyy) วันที่ (วัน/เดือน/ปี)	
Name(s) of Assessor(s) รายชื่อผู้ลงบันทึก	
Identification Number รหัสประจำจุดเฝ้าสังเกต	
Description of spot คำบรรยายจุดเฝ้าสังเกต	
What is being monitored at this spot? กำลังเฝ้าสังเกตอะไรอยู่ ☐ Wood ไม้ ☐ Nails ตะปู ☐ Concrete column เสาปูน ☐ Paint สี ☐ Other (please specify) อื่นๆ (โปรดระบุ) ____________________	

Section 2A - If this spot was just repaired	**ส่วนที่ 2A - ถ้าจุดนี้ได้รับการซ่อมแซมแล้ว**
What method(s) were used at this spot? ได้ใช้วิธีการซ่อมแซมใดในจุดเฝ้าสังเกตนี้	

Section 2B - If this spot has not been repaired		ส่วนที่ 2B - ถ้าจุดนี้ยังไม่ได้รับการซ่อมแซม
Condition of spot สภาพของจุดเฝ้าสังเกต	1	No damage ไม่มีความเสียหาย
	2	Minor damage (noticeable upon close inspection) มีความเสียหายเล็กน้อย (เห็นได้ชัดถ้าสังเกตใกล้ๆ)
	3	Moderate damage (noticeable) มีความเสียหายมาก (เห็นได้ชัด)
	4	Severe damage มีความเสียหายรุนแรง
Notes and observations สิ่งที่สังเกตเห็น		
Recommended management actions คำแนะนำในการซ่อมแซมหรือดูแลรักษา		

Section 3 – Other Information	ส่วนที่ 3 - ข้อมูลอื่นๆ
Temperature อุณหภูมิ °C	Relative Humidity ความชื้นสัมพัทธ์ %
Date of next monitoring (dd/mm/yyyy) วันที่ในการสังเกตครั้งต่อไป	

Photo
รูปภาพ

Guide to Baseline Monitoring Form

This form is used when monitoring a spot for the first time, whether it be after preservation has been performed, or if it is waiting for restoration.

Section 1 – Background Information

Date – The date of monitoring written in dd/mm/yyyy format.

Names(s) of Assessor(s) – List the names of all those who are performing the monitoring.

Identification Number – Code used to mark the spot being monitored.

The Identification Number should be written so as to be understood easily by those performing monitoring. The following is a suggested system of labeling monitoring spots:

From the grid plan of the Mrigadayavan Palace (<u>ผังแสดงการแบ่งพื้นที่พระราชนิเวศน์มฤคทายวัน</u> หรือ <u>ผังวังแบบกริด</u>), The buildings are already labeled with numbers, and the walkways are labeled with letters. Thus, for a six-digit code, the first two digits can be the number of the building (ex: 04, 05, 11) or the letter of the walkway preceded by a zero (ex: 0A, 0J).

The next two digits might be used to identify the floor. For example, 00 can be used for the ground floor and 01 can be used for the top floor.

The last two digits can be a running number, so that there can be many monitoring spots in one area as deemed necessary.

For example, if a monitoring spot was set up in the middle of walkway F on the top floor, then its identification number would be 0F0113. (13 would represent that this spot is the 13th spot monitored along all of walkway F.

Description of spot – Describe the exact spot being monitored, so that it can be pinpointed exactly in following monitoring activities.

What is being monitored – Check all materials that are being monitored at this spot. Can monitor more than one item if necessary.

Section 2A – Fill in this section <u>only if</u> this spot has been repaired and starting monitoring for the first time

What method(s) were used at this spot – Describe all the preservatives, finishes, or any chemicals that were used for preservation. Be as detailed as possible.

Section 2B – Fill in this section only if this spot is awaiting repair

Condition of spot – Circle the number that fits most with the condition of the monitoring spot.

1 – No damage – Everything looks fine and nothing needs to be done

2 – Minor damage (noticeable upon close inspection) – From far away, this spot looks fine, but if inspected closely, there are some minor problems such as some rust forming, or wood has scratch marks

3 – Moderate damage (noticeable) – From far away, this spot is noticeably damaged or problematic

4 – Severe damage – This should be selected only if the spot is damaged beyond repair and needs attention immediately either naturally or from unforeseen circumstances such as damage from a storm or from vandalism

Notes and observations – Describe in detail what is observed

Recommended management actions – Write down what is recommended to be done. Some recommendations can be found in the Monitoring Manual. If not found, contact an expert to understand what can be done.

Section 3 – Other Information

Temperature and humidity may be measured to compare differences across different spots.

Temperature (°C) – (optional) The temperature, in Celsius, of the monitoring spot.

Relative Humidity (%) – (optional) The relative humidity of the monitoring spot.

Date of next assessment – Important. Record the date in dd/mm/yyyy format of the next monitoring as recommended by the Guide to Test Method Monitoring Log.

Photo – Take a photo of the spot being monitored to keep an unbiased record of images. Try to use the same camera at every monitoring, use the same angle every time, and have a color chart in the photo to keep colors consistent. Photos can be compared to view changes over time, and photos should be kept in an organized fashion.

คู่มือเอกสารการเฝ้าสังเกตเบื้องต้น

ให้ใช้เอกสารการเฝ้าสังเกตเบื้องต้นในการเฝ้าสังเกตจุดสังเกตการณ์ใดเป็นครั้งแรกหลังจากการซ่อมแซมหรือในการเฝ้าสังเกตจุดสังเกตการณ์ใดเป็นครั้งแรกระหว่างรอการซ่อมแซม

ส่วนที่ 1 - ข้อมูลพื้นฐาน

วันที่ – วันที่ในการสังเกตการณ์ ให้ใช้รูปแบบ วัน/เดือน/ปี

รายชื่อผู้ลงบันทึก– ให้ผู้ที่ทำการเฝ้าสังเกตการณ์ครั้งนี้ลงชื่อในช่องนี้

รหัสประจำจุดเฝ้าสังเกต – เป็นรหัสประจำจุดที่จะเฝ้าสังเกต

รหัสประจำจุดเฝ้าสังเกตควรเป็นการตั้งขึ้นมาเพื่อให้ระบุอย่างง่ายดายว่าจุดนั้นตั้งอยู่ตรงไหน และคนที่เฝ้าสังเกตควรทำความเข้าใจ การตั้งรหัสต่อไปนี้เป็นตัวอย่างหนึ่งในการระบุจุดเฝ้าสังเกต

จาก ผังแสดงการแบ่งพื้นที่พระราชนิเวศน์มฤคทายวัน หรือ ผังวังแบบกริด พระที่นั่งต่าง ๆ ถูกระบุด้วยตัวเลข และทางเดินเชื่อมถูกระบุด้วยตัวอักษรภาษาอังกฤษ เพราะฉะนั้น ถ้าจะใช้รหัสประจำจุดที่มีหกหลัก

ให้สองหลักแรกระบุเลขของพระที่นั่ง (เช่น 04, 05, 11) หรือตัวอักษรของทางเดินเชื่อมโดยนำเลขศูนย์ไว้ข้างหน้า (เช่น 0A, 0J)

ให้สองหลักต่อไปใช้ระบุชั้น เช่นใช้ 00 สำหรับชั้นล่าง และ 01 สำหรับชั้นบน

ให้สองหลักสุดท้ายเป็นการรันหมายเลข ทำให้สามารถมีได้หลายจุดในบริเวณหนึ่ง

เช่น ถ้าจุดเฝ้าสังเกตตั้งอยู่ตรงมุขที่อยู่ตรงกลางของทางเดินเชื่อมระหว่างพระที่นั่งฝ่ายหน้า-ฝ่ายใน ให้ตั้งรหัสประจำจุดว่า 0F0113 (เป็นจุดที่ 13 ในทางเดินเชื่อมนี้)

คำบรรยายจุดเฝ้าสังเกต – ให้บรรยายตำแหน่งของจุดเฝ้าสังเกตอย่างละเอียดเพื่อที่จะระบุจุดเดิมได้ในการเฝ้าสังเกตครั้งต่อ ๆ ไป

กำลังเฝ้าสังเกตอะไรอยู่ – ให้ระบุวัสดุทุกอย่างที่เฝ้าสังเกตอยู่ หากจำเป็นสามารถเฝ้าสังเกตได้มากกว่าหนึ่งอย่างในจุดนึง

ส่วนที่ 2A - ให้เติมส่วนนี้ถ้าจุดนี้ได้รับการซ่อมแซมแล้วและกำลังเฝ้าสังเกตการณ์เป็นครั้งแรกหลังซ่อม

ได้ใช้วิธีการซ่อมแซมใดในจุดเฝ้าสังเกตนี้ – ให้ระบุสารเคมี น้ำยา สารเคลือบ หรือ วิธีที่ใช้ซ่อมแซมจุดนี้อย่างละเอียด

ส่วนที่ 2B – ให้เติมส่วนนี้ถ้าจุดนี้ยังไม่ได้รับการซ่อมแซม

สภาพของจุดเฝ้าสังเกต – ให้วงเลขที่เหมาะกับสภาพของจุดเฝ้าสังเกตนั้นมากที่สุด

1 – ไม่มีความเสียหาย – ทุกอย่างดูเป็นปกติ ไม่จำเป็นต้องทำอะไร

2 – มีความเสียหายเล็กน้อย (เห็นได้ชัดถ้าสังเกตใกล้ ๆ) – ถ้ามองไกล ๆ อาจดูเป็นปกติ แต่ถ้าสังเกตใกล้ ๆ อาจเห็นความผิดปกติเล็กน้อย เช่น หัวตะปูเริ่มมีสีสนิม หรือไม้มีรอยขีดข่วนหรือผุ

3 – มีความเสียหายมาก (เห็นได้ชัด) – ถ้ามองไกล ๆ สามารถเห็นได้ชัดว่าจุดนี้เริ่มเสียหายมากและอาจเป็นปัญหา

4 – มีความเสียหายรุนแรง – ควรเลือกข้อนี้หากจุดเฝ้าสังเกตเสียหายจนไม่สามารถระบุจุดได้ ควรซ่อมแซมอย่างเร่งด่วน อาจเกิดจากการสลายของตัวมันเอง หรือจากเหตุที่คาดไม่ถึงเช่นเสียหายจากพายุหรือการทำลายทรัพย์สินโดยผู้ไม่หวังดี

สิ่งที่สังเกตเห็น – บรรยายสิ่งที่สังเกตเห็นอย่างละเอียด

คำแนะนำในการซ่อมแซมหรือดูแลรักษา – เขียนคำแนะนำว่าควรทำอะไรหรือซ่อมจุดนี้อย่างไรต่อไป คำแนะนำบางส่วนมีระบุไว้ใน คู่มือการเฝ้าสังเกต หากไม่พบคำแนะนำให้ติดต่อผู้เชี่ยวชาญเพื่อขอคำปรึกษาต่อไป

ส่วนที่ 3 – ข้อมูลอื่น ๆ

อุณหภูมิและความชื้นสัมพัทธ์อาจใช้ในการเทียบจุดเฝ้าสังเกตต่าง ๆ หากสนใจบันทึก

อุณหภูมิ (°C) – (หากสนใจลงบันทึก) อุณหภูมิของจุดเฝ้าสังเกต ระบุเป็นองศาเซลเซียส

ความชื้นสัมพัทธ์ (%) – (หากสนใจลงบันทึก) ความชื้นสัมพัทธ์ของจุดเฝ้าสังเกต

วันที่ในการสังเกตครั้งต่อไป – สำคัญ ให้ระบุวันที่ในการเฝ้าสังเกตการณ์ในครั้งต่อไป ความถี่ในการเฝ้าสังเกตสามารถอิงจากคู่มือการใช้งานตารางบันทึกการทดสอบ ใช้รูปแบบ วัน/เดือน/ปี

รูปภาพ – ให้บันทึกภาพของจุดเฝ้าสังเกตไว้ด้วยเพื่อเก็บเป็นบันทึก ให้ใช้กล้องตัวเดิมตลอด ถ่ายจากมุมเดิม หากเป็นไปได้ให้มีชาร์ตสีในรูปด้วยเพื่อเทียบกับรูปอื่น ๆ รูปภาพที่เก็บบันทึกไว้สามารถนำมาเทียบเพื่อสังเกตความเปลี่ยนแปลงและควรเก็บด้วยกันอย่างเป็นระเบียบ

MONITORING FORM

เอกสารการเฝ้าสังเกต

Section 1 – Background Information	**ส่วนที่ 1 – ข้อมูลพื้นฐาน**
Date (dd/mm/yyyy) วันที่ (วัน/เดือน/ปี)	
Name(s) of Assessor(s) รายชื่อผู้ลงบันทึก	
Identification Number รหัสประจำจุดเฝ้าสังเกต	
What is being monitored? กำลังเฝ้าสังเกตอะไรอยู่ ☐ Wood ไม้ ☐ Nails ตะปู ☐ Concrete column เสาปูน ☐ Paint สี ☐ Other (please specify) อื่นๆ (โปรดระบุ) ____________________	

Section 2 – Assessing Damage	**ส่วนที่ 2 - การประเมินความเสียหาย**
Condition of spot สภาพของจุดเฝ้าสังเกต	1 No change from last observation ไม่มีความเปลี่ยนแปลงจากครั้งที่แล้ว 2 Minor changes (noticeable upon close inspection) มีความเปลี่ยนแปลงเล็กน้อย (เห็นได้ชัดถ้าสังเกตใกล้ๆ) 3 Moderate changes (noticeable) มีความเปลี่ยนแปลงมาก (เห็นได้ชัด) 4 Severe damage มีความเสียหายรุนแรง
Notes and observations สิ่งที่สังเกตเห็น	

Recommended management actions คำแนะนำในการซ่อมแซมหรือดูแลรักษา

Section 3 – Other Information		ส่วนที่ 3 - ข้อมูลอื่นๆ	
Temperature อุณหภูมิ	°C	Relative Humidity ความชื้นสัมพัทธ์	%
Date of next monitoring (dd/mm/yyyy) วันที่ในการสังเกตครั้งต่อไป			

Photo รูปภาพ

Guide to Monitoring Form

This form is used for consequent monitoring assessments.

Section 1 – Background Information

Date – The date of monitoring written in dd/mm/yyyy format.

Names(s) of Assessor(s) – List the names of all those who are performing the monitoring.

Identification Number – Code used to mark the spot being monitored.

What is being monitored – Check all materials that are being monitored at this spot. Can monitor more than one item if necessary.

Section 2 – Assessing Damage

Condition of spot – Circle the number that fits most with the condition of the monitoring spot.

1 – No change from last observation – Everything looks the same as last monitoring

2 – Minor changes (noticeable upon close inspection) – Compared to last time, this spot looks fine from far away, but if inspected closely, there are some minor problems such as some rust forming, or wood has scratch marks

3 – Moderate changes (noticeable) – Compared to last time, this spot is noticeably damaged or problematic even from far away

4 – Severe damage – This should be selected only if the spot is damaged beyond repair and needs attention immediately either naturally or from unforeseen circumstances such as damage from a storm or from vandalism

Notes and observations – Describe in detail what is observed

Recommended management actions – Write down what is recommended to be done. Some recommendations can be found in the Monitoring Manual. If not found, contact an expert to understand what can be done.

Section 3 – Other Information

Temperature and humidity may be measured to compare differences across different spots.

Temperature (°C) – (optional) The temperature, in Celsius, of the monitoring spot.

Relative Humidity (%) – (optional) The relative humidity of the monitoring spot.

Date of next assessment – Important. Record the date in dd/mm/yyyy format of the next monitoring as recommended by the Guide to Test Method Monitoring Log.

Photo – Take a photo of the spot being monitored to keep an unbiased record of images. Try to use the same camera at every monitoring, use the same angle every time, and have a color chart in the photo to keep colors consistent. Photos can be compared to view changes over time, and photos should be kept in an organized fashion.

คู่มือเอกสารการเฝ้าสังเกต

ให้ใช้เอกสารการเฝ้าสังเกตนี้ในการสังเกตครั้งต่อ ๆ มา หลังจากสังเกตการณ์ครั้งแรกไปแล้ว

ส่วนที่ 1 - ข้อมูลพื้นฐาน

วันที่ – วันที่ในการสังเกตการณ์ ให้ใช้รูปแบบ วัน/เดือน/ปี

รายชื่อผู้ลงบันทึก– ให้ผู้ที่ทำการเฝ้าสังเกตการณ์ครั้งนี้ลงชื่อในช่องนี้

รหัสประจำจุดเฝ้าสังเกต – เป็นรหัสประจำจุดที่จะเฝ้าสังเกต

กำลังเฝ้าสังเกตอะไรอยู่ – ให้ระบุวัสดุทุกอย่างที่เฝ้าสังเกตอยู่ หากจำเป็นสามารถเฝ้าสังเกตได้มากกว่าหนึ่งอย่างในจุดนึง

ส่วนที่ 2 - การประเมินความเสียหาย

สภาพของจุดเฝ้าสังเกต – ให้วงเลขที่เหมาะกับสภาพของจุดเฝ้าสังเกตนั้นมากที่สุด

1 – ไม่มีความเปลี่ยนแปลงจากครั้งที่แล้ว – ทุกอย่างดูเป็นปกติเทียบกับการเฝ้าสังเกตครั้งที่แล้ว ไม่จำเป็นต้องทำอะไร

2 – มีความเปลี่ยนแปลงเล็กน้อย (เห็นได้ชัดถ้าสังเกตใกล้ ๆ) – เทียบกับครั้งที่แล้ว ถ้ามองไกล ๆ อาจดูเป็นปกติแต่ถ้าสังเกตใกล้ ๆ อาจเห็นความผิดปกติเล็กน้อย เช่น หัวตะปูเริ่มมีสีสนิม หรือไม้มีรอยขีดข่วนหรือผุ

3 – มีความเปลี่ยนแปลงมาก (เห็นได้ชัด) – เทียบกับครั้งที่แล้ว ถ้ามองไกลๆ สามารถเห็นได้ชัดว่าจุดนี้เริ่มเสียหายมากและอาจเป็นปัญหา

4 – มีความเสียหายรุนแรง – ควรเลือกข้อนี้หากจุดเฝ้าสังเกตเสียหายจนไม่สามารถระบุจุดได้ ควรซ่อมแซมอย่างเร่งด่วน อาจเกิดจากการสลายของตัวมันเอง หรือจากเหตุที่คาดไม่ถึงเช่นเสียหายจากพายุหรือการทำลายทรัพย์สินโดยผู้ไม่หวังดี

สิ่งที่สังเกตเห็น – บรรยายสิ่งที่สังเกตเห็นอย่างละเอียด

คำแนะนำในการซ่อมแซมหรือดูแลรักษา – เขียนคำแนะนำว่าควรทำอะไรหรือซ่อมจุดนี้อย่างไรต่อไป คำแนะนำบางส่วนมีระบุไว้ใน คู่มือการเฝ้าสังเกต หากไม่พบคำแนะนำให้ติดต่อผู้เชี่ยวชาญเพื่อขอคำปรึกษาต่อไป

ส่วนที่ 3 – ข้อมูลอื่น ๆ

อุณหภูมิและความชื้นสัมพัทธ์อาจใช้ในการเทียบจุดเฝ้าสังเกตต่าง ๆ หากสนใจบันทึก

อุณหภูมิ (°C) – (หากสนใจลงบันทึก) อุณหภูมิของจุดเฝ้าสังเกต ระบุเป็นองศาเซลเซียส

ความชื้นสัมพัทธ์ (%) – (หากสนใจลงบันทึก) ความชื้นสัมพัทธ์ของจุดเฝ้าสังเกต

วันที่ในการสังเกตครั้งต่อไป – สำคัญ ให้ระบุวันที่ในการเฝ้าสังเกตการณ์ในครั้งต่อไป ความถี่ในการเฝ้าสังเกตสามารถอิงจากคู่มือการใช้งานตารางบันทึกการทดสอบ ใช้รูปแบบ วัน/เดือน/ปี

รูปภาพ – ให้บันทึกภาพของจุดเฝ้าสังเกตไว้ด้วยเพื่อเก็บเป็นบันทึก ให้ใช้กล้องตัวเดิมตลอด ถ่ายจากมุมเดิม หากเป็นไปได้ให้มีชาร์ตสีในรูปด้วยเพื่อเทียบกับรูปอื่น ๆ รูปภาพที่เก็บบันทึกไว้สามารถนำมาเทียบเพื่อสังเกตความเปลี่ยนแปลงและควรเก็บด้วยกันอย่างเป็นระเบียบ

Test Method Monitoring Log

Method under test: ………

Approximate service life: ………………………. or ☐ unknown   Recommended interval of monitoring: ……………………………

Concluded service life from test: ………………………………………………………………………………………………..

Date	Temperature (°C)	Relative Humidity (%)	Observations and notes	Signature of assessor	Date of next assessment	Signature after next assessment

Page number ____

Guide to Test Method Monitoring Log

This monitoring log is used to keep a systematic record when monitoring the effectiveness and/or lifespan of a preservative method.

Method under test –	State the chemicals or substances used, and describe what is being monitored.
Approximate service life –	State the approximate service life of the method being tested as given in the Monitoring Manual, if approximate service life is unknown, check the box labeled unknown.
Recommended interval of monitoring –	State the time interval between each observation.

Approximate service life	Recommended interval of monitoring
4 months	2 weeks
6 months	1 month
1 year	2 months
2 years	4 months
5 years	1 year
10 years	2 years

For an unknown service life, the recommended interval of monitoring is every 2 weeks.

For substances that are of natural origin, the recommended interval of monitoring is every week.

Concluded service life for test –	State the observed service life after the method being tested wears off or seems to no longer be effective. Filled in after test is complete.
Date –	The date of observation. Start from the date when the method being tested is first used.
Temperature (°C) –	(optional) The temperature, in celsius, of the room or area where the test is taking place.
Relative Humidity (%) –	(optional) The relative humidity of the room or area where the test is taking place.
Observations and notes –	Record observations and any changes here.
Signature of assessor –	The assessor signs their name here.
Date of next assessment –	Record the date of the next observation. Calculated from the recommended interval of monitoring.
Signature after next assessment –	The assessor who performs the next assessment will come back to sign this space after the next assessment is finished.

Monitoring Manual

Wood

To monitor wood, check for puddles of water, bleaching of color, dark stains, fruiting bodies, decay, or flaking of paint (if wood is painted).

1. If there are **puddles of water**, try to remove the water as soon as possible. Puddles may indicate that there are underlying structural faults, therefore experts on architecture or civil engineering should be consulted.
2. If the **wood has bleached or grayed**, this may indicate that the wood has been exposed to UV radiation and is dry. Applying new coats of teak oil and then sealing with wax or teak sealer is recommended. Otherwise, deck stain can be reapplied.
3. If there are **dark stains on the wood**, check to see if these stains are coming from nails or on the wood itself. If the stains are found around nails, refer to point 2 of the **Nails** section. If the dark stains are found on wood without the presence of nails, this may indicate the growth of fungi. Refer to the **Removing Fungi** section of this manual to remove the fungi.
4. If **fruiting bodies** are found growing on the wood, refer to the **Removing Fungi** section of this manual to remove the fungi.
5. If **parts of the wood has decayed**, use wood filler or epoxy to plug in the holes. If a large part of the wood has decayed, punch out the decayed parts and replace with wood from elsewhere.
6. If **paint is flaking off the wood**, this indicates that the wood underneath contains moisture. Remove the paint, let the wood dry, and reapply paint.

Nails

To monitor nails, check for the change in color of the head of the nail and if the rust from the nails has stained and spread onto the surrounding wood.

1. If only the **head of the nail has started to rust and change color** to red, brown, or black, tannic acid can be directly applied on the head of the nail to prevent the nail from further rusting without having to remove the rust first.
2. If **rust stains have spread** around the head of the nails onto the surrounding wood, the stain on the wood can be cleaned with oxalic acid. This means that the rust has covered

most of the nail, so the nail itself should be coated with tannic acid or replaced with a new stainless steel nail.

Concrete

To monitor concrete columns, check for rust stains, cracking, or spalling. Concrete columns should be monitored every 5 years.

1. If there are **rust stains** present on concrete columns with internal reinforcing bars, the stains can be cleaned with oxalic acid or other ways to remove rust.
2. If the column has **started to crack**, there may be a problem with the weight it is receiving. Consult an expert on architecture or civil engineering.
3. If the column has **spalled** enough to reveal internal rebars, but the **rebars are not rusted**, the column can be patched up with a cement mixture.
4. If the column has **spalled** enough to reveal that the **internal rebars are extremely rusted**, the whole column should be replaced.

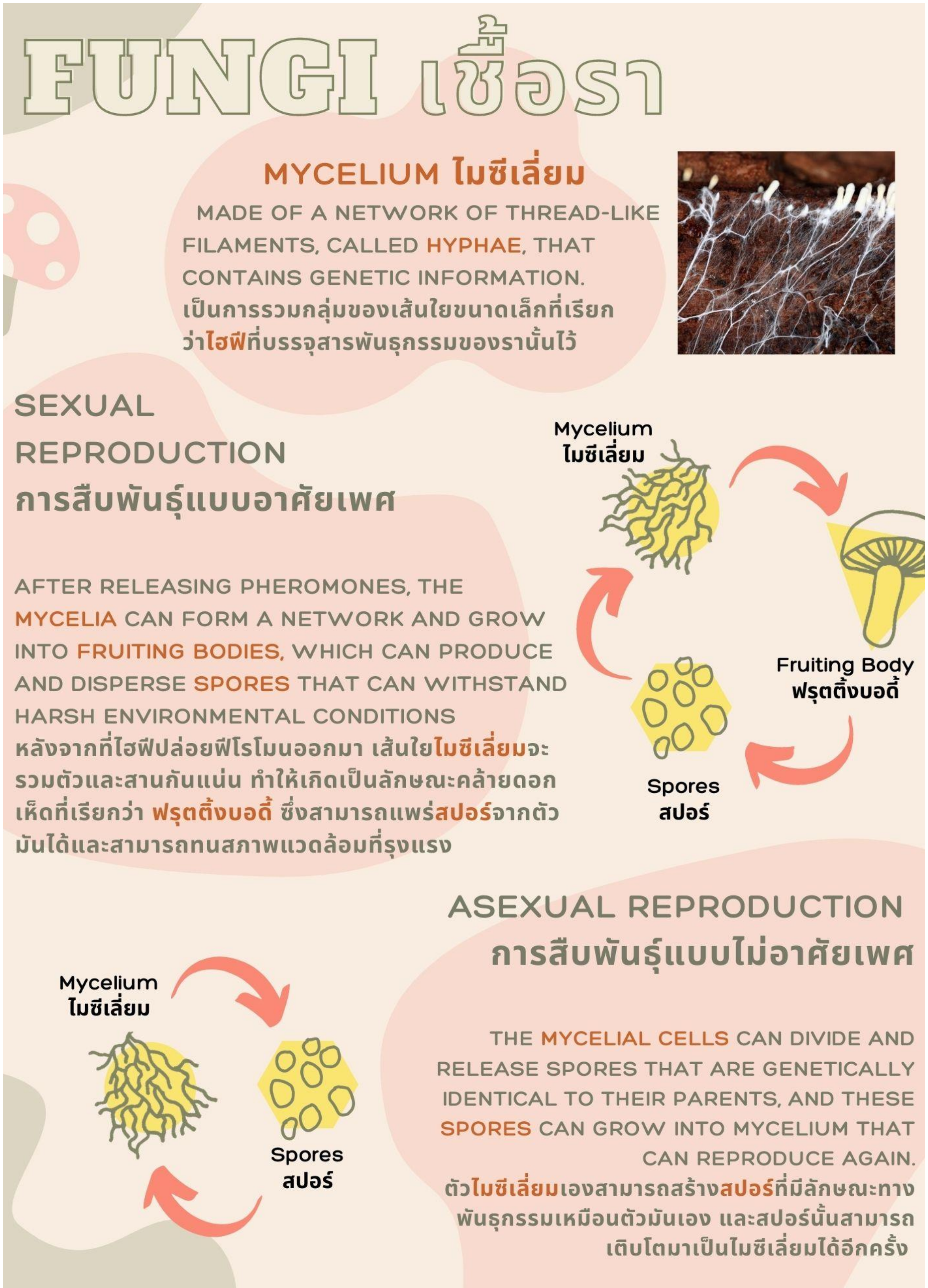
Removing Fungi

Fungi can be removed with the use of a 0.37% hypochlorite solution. If the fungi are not removed, 3% hypochlorite solution should be used instead. If there is a fruiting body, remove it first by picking or cutting it out. Apply the solution to the affected area for two minutes, then scrub it off. Make sure to dry the wood before applying wood preservatives or finishes. Contact an expert to dry wood in a kiln and to apply wood preservatives through the pressurizing method. **Warning:** Hypochlorite solutions should be used with care and in well-ventilated areas. Using Dettol Hygiene Multi-Use Disinfectant is an alternative for hypochlorite solution for less ventilated areas.

Approximate Service Life of Different Materials

Teak oil	6 months in areas exposed to high UV radiation
Teak sealer	1 year
Wax	6 months to 1 year
Deck stain	1-2 years
Stainless steel nails	50 years
Epoxy-coated rebars	55 years
Zinc-coated rebars	100 years
Stainless steel rebars	More than 100 years

Appendix D - Infographics and QR Codes



Fungi Removal

วิธีกำจัดเชื้อรา

REMOVE FUNGI IS BY USING **HYPOCHLORITE**, WHICH CAN BE FOUND IN BLEACH OR CLEANING PRODUCTS.
กำจัดเชื้อราด้วย ไฮโปคลอไรท์ ซึ่งเป็นส่วนผสมในน้ำยาฟอกขาว

USE **0.37%** HYPOCHLORITE TO REMOVE FUNGI AND **3%** HYPOCHLORITE FOR FUNGI THAT IS HARDER TO REMOVE
ใช้ไฮโปคลอไรท์ 0.37% เพื่อกำจัดเชื้อรา และไฮโปคลอไรท์ 3% สำหรับเชื้อราที่กำจัดยาก

APPLY THE SOLUTION OF HYPOCHLORITE TO THE FUNGI ON WOOD. LEAVE IT FOR **TWO MINUTES**, AND THEN WIPE IT OFF.
ทาสารละลายลงบนเชื้อราบนแผ่นไม้และทิ้งไว้ 2 นาที จึงเช็ดออก

WARNING! USE IN **WELL-VENTILATED AREAS**.
คำเตือน! ใช้ในบริเวณที่**อากาศถ่ายเทสะดวก**

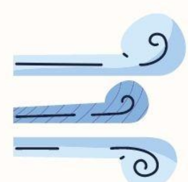
What causes RUST?

สนิมเกิดจากอะไร?

water/humidity
น้ำ/ความชื้น

oxygen
ออกซิเจน

sea salt spray
ละอองเกลือจากทะเล



accelerator
เกลือเป็นตัวเร่ง
การเกิดสนิม

Corrosion	=	metal	+	water	+	oxygen
การกัดกร่อน		เหล็ก		น้ำ		ออกซิเจน

Sources:
[1] https://www.hindawi.com/journals/cje/2013/784186/
[2] https://www.armorvci.com/corrosion/types-of-rust/

How many types of rust

สนิมมีกี่ชนิด

There are mainly 4 types of rust

สนิมสามารถแบ่งได้เป็น **4** ชนิดหลักๆ

1 Red Rust
สนิมแดง

Can be formed due to high oxygen and water exposure

สามารถเกิดได้ในบริเวณที่มีน้ำและออกซิเจนปริมาณสูง

Sources:
[1] https://www.hindawi.com/journals/cje/2013/784186/
[2] https://www.armorvci.com/corrosion/types-of-rust/

How many types of rust

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สนิมสามารถแบ่งได้
เป็น 4 ชนิดหลักๆ

2 Yellow Rust
สนิมเหลือง

Occurs in high moisture content areas, usually around puddles or standing water areas.

สามารถเกิดได้ในบริเวณที่มีปริมาณความชื้นหรือน้ำอยู่สูง ส่วนมากจะเกิดในบริเวณที่มีน้ำขังมากๆ

Sources:
[1] https://www.hindawi.com/journals/cje/2013/784186/
[2] https://www.armorvci.com/corrosion/types-of-rust/

How many types of rust

สนิมมีกี่ชนิด

There are mainly 4 types of rust

สนิมสามารถแบ่งได้เป็น 4 ชนิดหลักๆ

3 Brown Rust
สนิมน้ำตาล

Can be formed in areas where there is high oxygen and low moisture

สามารถเกิดขึ้นในบริเวณที่มีปริมาณออกซิเจนสูง และปริมาณความชื้นต่ำ

Sources:
[1] https://www.hindawi.com/journals/cje/2013/784186/
[2] https://www.armorvci.com/corrosion/types-of-rust/

How many types of rust

สนิมมีกี่ชนิด

There are mainly 4 types of rust

สนิมสามารถแบ่งได้เป็น **4** ชนิดหลักๆ

4 Black Rust
สนิมดำ

Can be formed in limited oxygen and low moisture areas

สามารถเกิดได้ในบริเวณที่มีปริมาณออกซิเจนและความชื้นน้อยหรือต่ำมากๆ

Sources:
[1] https://www.hindawi.com/journals/cje/2013/784186/
[2] https://www.armorvci.com/corrosion/types-of-rust/

METHODS OF REMOVING RUST
วิธีการกำจัดสนิม

- white vinegar/ white vinegar + lemon juice
  น้ำสมสายชู/ น้ำส้มสายชู + น้ำมะนาว
- molasses + water
  กากน้ำตาล + น้ำ

- salt + lime
  เกลือ + มะนาว
- potato + dish soap
  มันฝรั่ง + น้ำยาล้างจาน
- baking soda + water
  เบกกิ้งโซดา + น้ำ

GREENER WAYS TO PREVENT RUST ???

Tannic acid
กรดแทนนิก

a complex organic acid
กรดอินทรีย์ที่มีโมเลกุลใหญ่
และโครงสร้างซับซ้อน

applied onto a rusted surface
to convert the rust into a
protective layer
ใช้ทาลงบนพื้นผิวที่เป็นสนิมเพื่อเปลี่ยน
สนิมให้เป็นชั้นปกป้องเหล็ก ป้องกันสนิม

รู้หรือไม่ ?
สารสกัดจากธรรมชาติ
ช่วยป้องกันสนิมและ
เชื้อราได้

Aloe Vera
ว่านหางจระเข้

a succulent plant species
พืชอวบน้ำ มีน้ำจำนวนมากหล่อ
เลี้ยงอยู่ภายในเนื้อเยื่อของพืช

Asafoetida
มหาหิงคุ์

dried gum resin extract
obtained from plants of
the genus Ferula.
ยางที่ได้มาจากต้นไม้ใน
ตระกูลมหาหิงค์

used to coat clean iron
nails to inhibit rust
corrosion and protect the
nails against rusting
ใช้เคลือบลงบนพื้นผิวโลหะหรือ
เหล็กที่ต้องการจะป้องกันสนิม

Wood Preservatives
น้ำยารักษาเนื้อไม้

help reduce the damage cause by fungi or moisture
ช่วยปกป้องเนื้อไม้จากการถูกทำลายโดยเชื้อรา และความชื้น

Natural wood preservatives
น้ำยารักษาไม้แบบธรรมชาติ

can be extracted from bark, leaves, fruit, and seeds of plants. Examples are mimosa plants and quebracho trees.

สกัดมาจากส่วนต่างๆ ของต้นไม้หรือพืช เช่น เปลือกไม้ ใบไม้ ผลไม้ หรือ เมล็ด ตัวอย่างเช่นสารสกัดจากต้นไมยราบและต้นเคบราโช

Synthetic wood preservatives
น้ำยารักษาไม้ชนิดที่ใช้สารเคมี

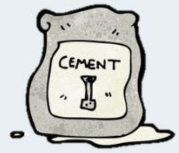
Examples are Copper chrome arsenate (CCA), Copper chrome borate (CCB), and Micronized copper azole (MCA).

ใช้สารเคมีในการช่วยรักษา ปกป้องเนื้อไม้ ตัวอย่างน้ำยามีซีซีเอ ซีซีบี และเอ็มซีเอ

In Thailand, the weather is hot and humid, so limiting moisture is important to protect wood from degradation.

ประเทศไทยมีสภาพอากาศร้อนชื้น และความชื้นนั้นสามารถเร่งการผุกร่อนของไม้ได้ การควบคุมความชื้นในเนื้อไม้จึงเป็นสิ่งสำคัญ

WHAT IS CONCRETE?
คอนกรีตคืออะไร?



cement
ปูนซีเมนต์

+

fine aggregates
(sand)
วัสดุผสมแบบละเอียด
(ทราย)

+

coarse aggregates
(rocks, gravel)
วัสดุผสมแบบหยาบ
(หิน กรวด)

+

water
น้ำ

To prolong the deterioration of concrete columns:
เพื่อป้องกันการเสื่อมสภาพของเสาคอนกรีต

thickness of concrete
= 1.5-3 inches
ความหนาของคอนกรีตหุ้มเหล็กเสริม = 1.5 - 3 นิ้ว

use concrete mixture
ex. fly ash, polymer
ใช้สารผสมในคอนกรีต เช่น เถ้าลอย โพลิเมอร์

use coated rebars
ex. epoxy-coated
ใช้เหล็กเส้นแบบเคลือบ เช่น เหล็กเส้นสีเขียว

AGENTS CORRODING REBARS
การกัดกร่อนของเหล็กเสริม

- water/humidity
  น้ำ/ความชื้น
- carbon dioxide
  คาร์บอนไดออกไซด์
- chlorides from natural water or salt spray
  คลอไรด์ (จากน้ำ/ละอองเกลือจากทะเล)

sources:
[1]http://subsites.dpt.go.th/edocument/images/pdf/sd_work/MRT05.pdf

Life Cycle of Fungi
ชีวิตของเชื้อรา

Fungi Removal
กำจัดเชื้อราอย่างไรดี?

What Causes Rust?
สนิมเกิดขึ้นได้อย่างไร?

How Many Types of Rust?
สนิมมีกี่ชนิด?

Greener Ways to Prevent Rust
ป้องกันสนิมด้วยสารสกัดธรรมชาติ

Methods of Removing Rust
กำจัดสนิมอย่างไรดี?

What is Concrete?
คอนกรีตคืออะไร?

Wood Preservatives
น้ำยารักษาเนื้อไม้

Example of implementation of QR Codes onto the pillars of the palace walkways.

Appendix E - Comparison of Polymer Properties

How polymers compare with one another

	Acrylic	Styrene Acrylic	VAE	SBR	PVA
Adhesion	3	2	4	1	5
Breathability	1	2	5	5	3
UV Stability	1	2	3	5	4
Waterproof ability	2	3	4	1	5
Re-wetting ability	3	4	2	5	1
Cost	1	2	3	4	5

1 = Most or best
5 = Least or poorest

Reprinted from *Understanding Polymers in Concrete* by Nasvik, J. (2001).

Appendix F - Types of Metals Used in Sacrificial Anodes

Type of anode	Zinc	Aluminium	Magnesium
Suitable conditions	- Seawater - Iron rebars	- Seawater and brackish water - Carbon steel and iron rebars	- Freshwater - Carbon steel and iron rebars

Adapted from *Corrosion Technologies: Innovation for Corrosion Control* by Thai Marine Protection. (2020).