



พระราชวังเวศน์มฤคทายวัน
MRIGADAYAVAN PALACE
美麗閣夏宮

**Restoring Mrigadayavan Palace:
Understanding the Causes of the Wood Deterioration Process and
Providing Guidelines for the Protection of Old Wooden Buildings**

**An Interactive Qualifying Project and Interactive Science and Social Project
Final Report**

Sponsored by

The Mrigadayavan Palace Foundation

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Abstract

At the Mrigadayavan Palace, the problem of wood deterioration due to the growth of fungi is becoming the main focus of the restoration plan. This problem is the main obstacle to preserving the palace's authenticity while retaining most of the original old wood. Hence, the main goal of this project is to help the Mrigadayavan Palace Foundation understand the causes of wood deterioration by mold and recommend an appropriate maintenance plan. To accomplish this, the team analyzed the information obtained through observations, research, case studies, and interviews with the palace staff and various experts in fungi and wood. Through the process, we have gained insights and valuable information. We prepared an easy-to-understand report on how mold decays wood for our sponsor, together with recommendations for preventive actions to stop wood decay by mold. We also provided a user-friendly guideline to evaluate the effectiveness of mold preventative options for future restoration work.

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Executive Summary

Introduction

The Mrigadayavan Palace, located seaside in Cha-am district, Phetchaburi, was a vacation residence that was constructed in 1924 for His Majesty King Vajiravudh (King Rama VI). His Majesty designed the palace, combining Thai and Western elements and merging the environment with the architecture. In 1981, the palace was officially registered as a national historic site by the Fine Arts Department of Thailand, and renovations to restore it began. The Mrigadayavan Palace Foundation was founded in 1992 and aims to preserve the original structure of the palace. Through continuous conservation efforts, they have successfully achieved their goal of maintaining the Mrigadayavan Palace for future generations.

Problem

Due to the location and extensive use of teak wood for building the main structures and walkways, the palace has faced wood decay by molds and fungi for years. Hence, the Mrigadayavan Palace Foundation would like to understand the causes of deterioration that make the wood structures decay, and the methods of restoration that do not cause harm to the wood surface. Furthermore, the foundation would like a set of guideline recommendations for wooden building protection and is also interested in indigenous knowledge about herbal oils and extracts. Thus, the team investigated these issues and gathered information to fulfill their ultimate goal of preserving the palace.

Goal

The goal of this project was to understand the causes of the deterioration process of wood so that appropriate preventive actions can be selected to prevent further damage to the wooden buildings at the Mrigadayavan Palace.

Objectives and Methodology

Our team had five objectives to accomplish these goals:

1. Observe the structural damages and select the areas of study at the Mrigadayavan Palace.

The team qualitatively observed the areas of the palace where fungal growth and the breakdown of the wooden structures occurred, interviewing the palace staff and current landscape architect to gain more information on the palace structure and concerned areas. In addition, consultations with experts on mold and wood conservation helped confirm the type of structural damage at the palace.

2. Understand the wood deterioration process.

Our team focussed on scientific research and literature reviews. In addition, we interviewed the current landscape architect of the Mrigadayavan Palace to gain a deeper understanding of the structures of the palace and gathered case studies to aid in formulating effective strategies for tackling the issue.

3. Understand how mold propagates on wooden buildings.

Our team first considered the locations of the Mrigadayavan Palace near the coast, which contained high humidity. Interviews were conducted with the palace director, staff, and mold experts, including professors from the departments of botany and microbiology at Chulalongkorn University. Furthermore, we examined case studies of mold growth that have similar problems to the Mrigadayavan Palace.

4. Find practical preventive actions for wood deterioration.

More research documents and interviews from mold experts to determine which substances were suitable and effective in preventing and minimizing wood deterioration were gathered. In addition, our team conducted an experiment to test which chemicals could remove molds and considered the time it takes for molds to redevelop on the wood.

5. Provide a guideline booklet for wood deterioration to the Mrigadayavan Palace Foundation and people working at other old wooden buildings.

For the Mrigadayavan Palace Foundation to better understand the issues and the methods they have used for wood protection, our team has summarized our findings to create a guideline booklet (both in physical and digital format) for preventing wood deterioration. In

addition, there was a section about experimental protocols to test and compare the effectiveness of the mold-minimizing chemicals for future research.

Results and Analysis

1. Visually assessing the structural damage.

We selected the areas that were most concerning and should be focused on, which we concluded were areas B and J.

2. Molds and fungi were not the only factors that caused wood deterioration.

In addition to molds and fungi, sunlight and moisture affect wood deterioration. It was concluded from an interview at Ruen Urai (an old wooden house situated in Bangkok) that wood decay was due to sunlight exposure; when the protective paint layer on the wood peels off, the ultraviolet (UV) radiation from the sun can break down the lignin in the wood, leading to its degradation. In addition, Dr. Yuwarat Hemasilpin (an architect who is an expert on restoring wooden houses) informed us that wood decay is a collective result of accumulated moisture, causing the wood to swell, and was aided by strong winds which spread the fungi spores and salt from the sea.

3. The lack of staff limits the monitoring of damages and methods for the prevention and minimization of wood decay.

The lack of staff resulted in a lack of constant care for the palace. This is due to COVID-19 and the palace being closed to visitors.

4. Chemicals that are ineffective in eliminating molds and chemicals that may not be suitable for the palace.

As reported by the Mrigadayavan staff, Dettol and sodium hypochlorite were concluded to be ineffective in killing molds. It was later found out by Ajarn Jittra Piaphukeow (an expert on molds from the Department of Botany, Chulalongkorn University) that Dettol is an antiseptic solution that kills bacteria but has no effect on molds and that sodium hypochlorite solution used was mixed with water. When applied to the porous surface of wood, the water was trapped inside the wood after being absorbed by it. Thus, the wood became moist inside, promoting the growth of mold.

5. The need to specify the particular mold and fungi species was unnecessary since fungicides are designed to be effective on most species.

From the interviews with Ajan Jittra and Ajarn Panan, both have suggested that there is no need to identify the species of fungi and molds as, nowadays, fungicides have been designed to work with most species. Thus, such methods are not worth the money and time spent.

6. Chemicals that have the potential to eliminate molds.

Ajarn Jittra Piaphukeow (an expert on molds from the Department of Botany, Chulalongkorn University) recommended some chemicals which could eliminate molds: distilled vinegar, borax, and hydrogen peroxide. Our team also looked into more chemicals including chlorine dioxide, iodophor, and benzalkonium chloride.

7. New alternative methods.

From attending the Conservation and Carpentry Fair, we listened to Associate Professor Dr. Panipa Chaowana, who reviewed the technology used to protect the wood. We then researched new technologies that used this approach, including acetylation, thermal treatment, resins, and nanotechnology.

8. Green alternatives may not be as effective as expected.

Green alternatives are non-toxic chemicals and include lemon, fruit extracts that contain citric acid, and essential oils; however, during our research, it was found that most of these chemicals were ineffective and unsuitable for mold prevention and minimization at the palace, especially in the canopy area that is constantly in direct contact with sunlight, rain, and moisture.

9. Epoxy can be used to block the holes in porous areas as well as to repair the wood.

After we looked into more information and consulted with a conservation expert (Professor Craig Deller), it was found that epoxy can be used to repair wood by blocking the porous areas. This will prevent moisture from entering the wood, accelerate the process of wood deterioration, and restore the appearance of the wooden part closer to its original state.

10. Wood preservation processes.

The manual obtained from the Sanctuary of Truth (การป้องกันรักษาเนื้อไม้, *Wood Preservation*) contained information about wood protection. The wood preservation methods are to apply wood preservatives through wood cells to increase its durability, prevent moisture from penetrating, prevent mold growth and can be used for wood preparation. The methods include two main types, non-pressure and with pressure. The difference is the pressure processes will pass the preservatives deeper and more evenly through the wood by using an impregnating tank.

The Sanctuary of Truth uses the pressure process for their wood twice, before and after wood processing. This results in a longer lifespan of wood (over 30 years).

Recommendations

1. Recommendations for minimizing the growth of molds and fungi

We recommend some chemicals that effectively eliminate molds, which are borax and quaternary ammonium compounds (Benzalkonium Chloride or BKC). Moreover, we also recommend distilled vinegar (which contains acetic acid) and hydrogen peroxide for household mold remedies.

2. Recommendations for preventing moisture that causes the growth of molds and fungi

Molds and fungi can be prevented using different types of wood finishes such as paints. The paints that we recommend are Beger and Cutek brand paints. In addition, physical methods can be used, which include adding support or fixing the foundation and structure to prevent moisture from seeping in.

3. Recommendations for wood preparation

Wood impregnation and wood drying are used to prepare the wood. For wood impregnation, substances that may prevent the growth of molds will be soaked into the wood and work as a protective layer. For wood drying, the moisture content will be removed during the drying phase of the process.

4. Recommendations to prevent moisture in porous surfaces and modular design using epoxy

Epoxy resins can be used to cover up the gaps in the structures and is recommended to prevent the water from going inside. It is considered lightweight, strong, and durable and can last up to 20 years as long as proper maintenance is performed. Thus, it is suitable for application on wood canopies.

5. Recommendation for experimenting to test the effectiveness of the recommended method

We have recommended using chemicals that contain borax and BKC (which are the chemicals found to be in killing molds and fungi). Hence, we also advise the palace to experiment with these chemicals to test their effectiveness. The experimental procedures and monitoring form have been constructed, including the basic steps for the Mrigadayavan Palace staff to follow and experiment in the most straightforward approach.

บทสรุปผู้บริหาร

พระราชนิเวศน์มฤคทายวันตั้งอยู่ชายทะเลในอำเภอชะอำ จังหวัดเพชรบุรี สร้างขึ้นในปี พ.ศ. 2467 เพื่อถวายเป็นที่ประทับพักผ่อนแต่พระบาทสมเด็จพระปรมินทรมหาประชาธิปก (รัชกาลที่ 6) พระองค์ทรงออกแบบหมู่พระที่นั่งด้วยพระองค์เองโดยผสมผสานสถาปัตยกรรมไทยและตะวันตก เข้าด้วยกัน ในปีพ.ศ. 2524 พระราชนิเวศน์มฤคทายวันได้รับการขึ้นทะเบียนอย่างเป็นทางการให้เป็น โบราณสถานของชาติโดยกรมศิลปากร ในปีพ.ศ. 2535 ได้มีการก่อตั้งมูลนิธิพระราชนิเวศน์มฤคทายวันขึ้นเพื่อการอนุรักษ์อย่างต่อเนื่องโดยมีเป้าหมายที่จะอนุรักษ์โครงสร้างเดิมของพระราชนิเวศน์ที่ สมบูรณ์ไว้เพื่ออนุชนรุ่นหลัง

ปัญหา

เนื่องจากพระราชนิเวศน์มฤคทายวันเป็นอาคารไม้ดีดทะเล การก่อสร้างใช้ไม้สักทั้งหลัง โครงสร้างหลักและบริเวณทางเดินพระตำหนักจึงเผชิญกับการผุพังของไม้จากเชื้อรามาเป็นเวลา หลายปี มูลนิธิพระราชนิเวศน์มฤคทายวันต้องการทำความเข้าใจถึงสาเหตุการเสื่อมสภาพที่ทำให้โครงสร้างไม้ผุพังรวมถึงวิธีการบูรณะที่ไม่ก่อให้เกิดอันตรายต่อพื้น ไม้ ไม้ นอกจากนี้มูลนิธิฯ ยัง ต้องการคำแนะนำและแนวปฏิบัติสำหรับการป้องกันอาคารไม้อนุรักษ์อีกด้วย

เป้าหมาย

โครงการนี้มีเป้าหมายเพื่อทำความเข้าใจถึงสาเหตุและกระบวนการเสื่อมสภาพของไม้เพื่อ เลือกแนวทางป้องกันได้อย่างเหมาะสมและนำไปใช้ได้จริงในการอนุรักษ์หมู่พระที่นั่งไม้ในพระราช นิเวศน์มฤคทายวัน

วัตถุประสงค์และวิธีการ

คณะผู้วิจัยได้ตั้งวัตถุประสงค์ไว้ 5 ประการดังนี้:

1. สังเกตรูปแบบความเสียหายของโครงสร้างไม้เพื่อเลือกพื้นที่ศึกษา

คณะผู้วิจัยได้สังเกตหมู่พระที่นั่งไม้ของพระราชนิเวศน์มฤคทายวันเพื่อสังเกตรูปแบบความเสียหายของไม้จากรา และสัมภาษณ์เจ้าหน้าที่ของทางพระราชนิเวศน์มฤคทายวัน และสถาปนิกเพื่อให้ได้ข้อมูลเพิ่มเติมเกี่ยวกับโครงสร้างของพระราชนิเวศน์มฤคทายวันและ บริเวณที่มีการผุพังมากเป็นพิเศษ

2. เข้าใจกระบวนการเสื่อมสภาพของเนื้อไม้.

คณะผู้วิจัยได้ค้นคว้าหาข้อมูลเกี่ยวกับโครงสร้างของไม้และปัจจัยที่ทำให้ไม้ผุ คณะผู้วิจัยได้สัมภาษณ์ภูมิสถาปนิกของพระราชนิเวศน์มฤคทายวันเพื่อทำความเข้าใจ โครงสร้างของพระราชนิเวศน์ฯ อย่างลึกซึ้ง รวบรวมกรณีศึกษาเพื่อช่วยให้เข้าใจในสถานการณ์ และเพื่อทราบแนวทางการแก้ปัญหาที่มีประสิทธิภาพ

3. ทำความเข้าใจว่าเชื้อราแพร่กระจายบนอาคารไม่ได้อย่างไร

คณะผู้วิจัยได้พิจารณาสถานที่ตั้งของพระราชวังสนามจันทร์อุทยานซึ่งอยู่ใกล้ชายฝั่ง ทะเลที่มีความชื้นสัมพัทธ์สูง สัมภาษณ์ผู้อำนวยการและเจ้าหน้าที่ของมูลนิธิมฤตยาวัน สัมภาษณ์ผู้เชี่ยวชาญด้าน เชื้อราจากภาควิชาพฤกษศาสตร์และจุลชีววิทยา คณะวิทยาศาสตร์ จุฬาลงกรณ์ มหาวิทยาลัย นอกจากนี้ยังได้ตรวจสอบกรณีศึกษาเรื่องการเจริญเติบโต ของเชื้อราในบริบทคล้ายกับพระราชวังสนามจันทร์อุทยานอีกด้วย

4. ประเมินวิธีการป้องกันการเสื่อมสภาพของไม้แบบต่างๆ

คณะผู้วิจัยได้ค้นคว้าทฤษฎีและข้อมูลงานวิจัยที่เกี่ยวข้องเกี่ยวกับการเสื่อมสภาพ ของไม้ สัมภาษณ์ผู้เชี่ยวชาญด้านเชื้อรา เพื่อเข้าใจวิธีการป้องกันไม้เสื่อมสภาพจากเชื้อรา ค้นคว้าข้อมูลของสารป้องกันเชื้อราที่เหมาะสมและมีประสิทธิภาพ วางแผนการทดลอง เพื่อประเมินประสิทธิภาพของสารกำจัดเชื้อราที่ต้องการคัดกรอง

5. รวบรวมประเด็นสำคัญของงานวิจัยในรูปแบบคู่มือการกำจัดเชื้อราและการอนุรักษ์อาคารไม้

คณะผู้วิจัยได้สรุปประเด็นสำคัญในรูปแบบคู่มือและแนวทางปฏิบัติในการแก้ปัญหา ราในไม้และวิธีป้องกัน เพื่อให้มูลนิธิพระราชวังสนามจันทร์อุทยานมีความเข้าใจอย่างถูกต้องใน กระบวนการเสื่อมสภาพไม้ (ทั้งในรูปแบบสิ่งพิมพ์และดิจิทัล) คู่มือนี้ยังแสดงวิธีเปรียบเทียบ ประสิทธิภาพของสารเคมีลดเชื้อราสำหรับงานในอนาคตอีกด้วย

ผลลัพธ์และการวิเคราะห์

1. การประเมินความเสียหายของโครงสร้าง

คณะผู้วิจัยเลือกศึกษาพื้นที่ส่วน B และ J ของหมู่พระที่นั่งมีการผุพังจากเชื้อรามากที่สุด

2. เชื้อราไม่ใช่ปัจจัยเดียวที่ทำให้ไม้เสื่อมสภาพ

นอกจากเชื้อราแล้วแสงแดดและความชื้นก็เป็นปัจจัยสำคัญต่อการเสื่อมสภาพของ ไม้เช่นกัน สรุปได้จากการสัมภาษณ์เรือนอุไร (บ้านไม้เก่าในกรุงเทพฯ) ว่าไม้ผุเพราะแสงแดด เมื่อชั้นสีเคลือบบนไม้ลอกออก รังสีอัลตราไวโอเลต (UV) จากดวงอาทิตย์สามารถทำลาย ลิกนินในเนื้อไม้ทำให้เกิดการเสื่อมสภาพ นอกจากนี้ ดร.ยวรัตน์ เหมะศิลป์พิน (สถาปนิก-ผู้เชี่ยวชาญด้านการบูรณะบ้านไม้) เล่าว่า การผุพังของไม้เป็นผลรวมจากความชื้นสะสม ทำให้ ไม้บวม แรงลมจะพัดสปอร์ของเชื้อราเข้าไปในเนื้อไม้ และ ไอทะเลก็ทำให้การผุพัง ของไม้เกิดเร็วขึ้น

3. การขาดพนักงานจำกัดการตรวจสอบความเสียหายและวิธีการป้องกันและลดการผุพังของไม้

การขาดเจ้าหน้าที่ช่วงการระบาดของ COVID-19 ทำให้พระราชนิเวศน์ฯ ปิดให้บริการและมีการปลดพนักงาน ทำให้ตัวอาคารไม่ได้รับการดูแลอย่างทั่วถึง ส่งผลให้มีการ พงษ์ของหมู่พระที่นั่งมากขึ้น

4. ควรใช้สารเคมีที่มีประสิทธิภาพในการกำจัดเชื้อราในไม้เท่านั้น

จากการสัมภาษณ์เจ้าหน้าที่มฤคทายวัน เขตตลิ่งชันและโซเดียมไฮโปคลอไรด์ไม่มี ประสิทธิภาพในการฆ่าเชื้อรา อาจารย์ จิตรา เพ็ญภูเขียว (ผู้เชี่ยวชาญด้านรามาจากภาควิชา พฤษศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย) อธิบายว่าเขตตลิ่งชัน เป็นน้ำยาฆ่าเชื้อแบคทีเรีย ไม่มีผลต่อเชื้อรา ส่วนสารละลายโซเดียมไฮโปคลอไรด์ฆ่าเชื้อราได้ แต่เนื่องจากเป็นสาร ละลายน้ำ ไม่เหมาะกับผิวไม้ที่มีรูพรุน น้ำจะถูกดูดซึมเข้าไปและถูกขังอยู่ในเนื้อไม้ ความชื้น ในเนื้อไม้จะช่วยให้เชื้อราเจริญเติบโตและทำให้ไม้ผุมากขึ้น

5. สารฆ่าเชื้อราสามารถกำจัดเชื้อราทั่วไปได้ดี

ผู้เชี่ยวชาญด้านรา (อาจารย์จิตรา และ อาจารย์ปัทมน) ให้ข้อมูลตรงกันว่าสารฆ่า เชื้อราได้ถูกออกแบบให้ใช้ได้กับเชื้อราส่วนใหญ่ ดังนั้นจึงไม่จำเป็นต้องลงทุนระบุชนิดของ เชื้อราซึ่งมีค่าใช้จ่ายสูงและใช้เวลานาน

6. สารเคมีที่มีศักยภาพในการกำจัดเชื้อรา

อาจารย์จิตรา เพ็ญภูเขียว ได้แนะนำสารเคมีที่มีประสิทธิภาพในการกำจัดราทั่วไป 3 ชนิดคือ น้ำส้มสายชูกลั่น บอแรกซ์ และ สารละลายไฮโดรเจนเปอร์ออกไซด์ นอกจากนั้น แล้วคณะผู้วิจัยยังได้ค้นพบสารฆ่าเชื้อราอื่นๆ เพิ่มเติม เช่น คลอรีนไดออกไซด์ ไอโอโดฟอร์ และเบนซาลโคเนียมคลอไรด์

7. ทางเลือกใหม่ในการปกป้องเนื้อไม้

คณะผู้วิจัยได้เรียนรู้ถึงทางเลือกใหม่ในการปกป้องเนื้อไม้จาก ศาสตราจารย์ ดร.พรณนิภา เขาวนระ ในการบรรยายเรื่อง เทคโนโลยีปกป้องเนื้อไม้ เช่น กระบวนการ อะซิติกเลชัน การบำบัดด้วย ความร้อน การใช้เรซิน และนาโนเทคโนโลยี ที่นิทรรศการงานไม้อนุรักษ์ (Conservation Carpentry Fair, CCF 2023) 9-12 กุมภาพันธ์ 2023 มทร.ธัญบุรี

8. สารที่เป็นมิตรต่อสิ่งแวดล้อมอาจมีประสิทธิภาพในการกำจัดเชื้อราต่ำ

สารที่เป็นมิตรต่อสิ่งแวดล้อม เช่น มะนาว สารสกัดจากผลไม้ที่มีกรดซิตริก และ น้ำมันหอมระเหย ไม่มีประสิทธิภาพในการ ป้องกันไม้จากเชื้อรา โดยเฉพาะบริเวณกันสาด ที่ต้องสัมผัสกับแสงแดด ฝน และความชื้นตลอดเวลา

9. อีพ็อกซีสามารถใช้อุดรูพรุนในการซ่อมแซมเนื้อไม้

ศาสตราจารย์ Craig Deller ผู้เชี่ยวชาญด้านการอนุรักษ์ไม้แนะนำให้ใช้อีพ็อกซี่ อุดรูพรุนในการซ่อมแซมไม้ โดยอีพ็อกซี่จะ
ช่วยป้องกันไม่ให้ความชื้นเข้าสู่เนื้อไม้ ช่วยลด การเสื่อมสภาพของเนื้อไม้ และยังใช้เติมเต็มรูปลักษณ์เดิมของไม้ให้มีใกล้เคียงกับสภาพ
เดิม อีกด้วย

10. กระบวนการป้องกันไม้

คู่มือการรักษาเนื้อไม้ที่ได้รับมาจากปราสาทสัจธรรม (วิธีป้องกันรักษาเนื้อไม้อ่อนนุ่ม) มีข้อมูลเกี่ยวกับการรักษาเนื้อไม้ โดย
การทำนํ้ายารักษาเนื้อไม้ผ่านเซลล์เนื้อไม้เพื่อเพิ่มความ คงทน ช่วยป้องกันความชื้นซึมผ่าน ป้องกันเชื้อรา และสามารถนำไปใช้ในการเตรีย
มเนื้อไม้ ก่อนการซ่อมบำรุง โดยมีวิธีการอัดนํ้ายาปกป้องเนื้อไม้ 2 แบบ คือแบบไม่ใช้แรงดัน และแบบ ใช้แรงดัน กระบวนการใช้แรง
ดันจะใช้ถึงความดันอัดนํ้ายาไม่ทำให้นํ้ายาลง ไปในเนื้อไม้ได้ลึก และสม่ำเสมอมากขึ้นกว่าวิธีการทางกายภาพ เช่น ทาสี ปราสาทสัจ
ธรรมใช้กระบวนการอัด นํ้ายาไม้ 2 ครั้ง ก่อนและหลังการแปรรูปไม้ส่งผลให้ไม้มีอายุการใช้งานยาวนานขึ้น (มากกว่า 30 ปี)

ข้อเสนอแนะ

1. วิธีการลดการเจริญเติบโตของเชื้อรา

คณะผู้วิจัยมีความเห็นว่า การใช้สารเคมีที่มีประสิทธิภาพในการกำจัดเชื้อรา เช่น บอแรกซ์ และสารประกอบควอ
เทอร์นารีแอมโมเนียม (Benzalkonium Chloride หรือ BKC) จะช่วยให้มูลนิธิพระราชนิเวศน์มฤคทายวันสามารถปกป้องเนื้อไม้จาก
การบุกรุกโดยราได้ อย่างมีประสิทธิภาพ นอกจากนี้ยังสามารถนำสารเคมีในครัวเรือนบางชนิด เช่น น้ำส้มสายชูกลั่น (กรดน้ำส้ม) และ
สารละลายไฮโดรเจนเปอร์ออกไซด์ (ยาล้างแผล) มาใช้ได้ด้วย

2. ป้องกันและลดความชื้นที่เป็นสาเหตุของการเจริญเติบโตของเชื้อรา

ปัญหาเรื่องเชื้อราสามารถป้องกันได้โดยการเลือกใช้วัสดุเคลือบไม้ประเภทต่างๆ สີที่ แนะนำคือสี Beger และ Cutek
นอกเหนือจากนี้ยังสามารถใช้วิธีการทางกายภาพ เช่นการ ปรับแต่ง และปรับโครงสร้างอาคารเพื่อป้องกันไม่ให้ความชื้นซึมเข้าไปใน
เนื้อไม้

3. การเตรียมไม้ให้เหมาะสม

การเคลือบไม้และการอบแห้งไม้เป็นวิธีการที่ใช้เพื่อการเตรียมไม้ก่อนนำไปใช้งาน วิธีการเคลือบไม้ทำได้โดยการแช่ไม้ในสาร
รักษาเนื้อไม้และป้องกันการเจริญเติบโตของ เชื้อราเพื่อให้สารนั้นซึมเข้าไปในเนื้อไม้และยังคงอยู่ในเนื้อไม้ตลอดอายุการใช้งาน การอบ
แห้งก็เป็นอีกวิธีหนึ่งที่สามารถลดความชื้นออกไปจากเนื้อไม้ได้

4. การป้องกันความชื้นเข้าไปในพื้นที่ที่มีรูพรุนและส่วนประกอบของอาคารแบบโมดูลาร์

ควรใช้อีพ็อกซี่เรซินปิดช่องว่างของไม้ที่มีรูพรุนและช่องว่างระหว่างชิ้นไม้เพื่อป้องกันไม่ให้นํ้าซึมเข้าไปด้านในและก่อให้เกิด
การพุพองของไม้ อีพ็อกซี่เป็นสารที่มีน้ำหนักเบา แข็ง แรง ทนทาน ใช้งานได้นานถึง 20 ปีถ้ามีการบำรุงรักษาอย่างเหมาะสม คณะผู้วิจัย
ขอแนะนำ ให้มูลนิธิพระราชนิเวศน์มฤคทายวันใช้อีพ็อกซี่เรซินปิดช่องว่างของกันสาด

5. การประเมินประสิทธิภาพของสารกำจัดเชื้อรา

คณะผู้วิจัยได้เลือกสารกำจัดเชื้อราประสิทธิภาพสูง 2 สูตรให้แก่มูลนิธิพระราช นิเวศน์มฤคทายวัน (บอแรกซ์ และ BKC)
โดยคณะผู้วิจัยได้ออกแบบวิธีการประเมิน ประสิทธิภาพซึ่งทีมงานสามารถนำไปใช้เป็นต้นแบบในการเปรียบเทียบสารเคมีหรือวิธีการ
กำจัดเชื้อราอื่นๆ ได้อีกในอนาคต

Authorship

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Acknowledgements	Nattapat	Napassarawadee
Executive Summary (English)	Napassarawadee	Kavinpat
Executive Summary (Thai)	Kavinpat, Thanatchaya, Rattanaphorn, Nattapat, Angsana	Kavinpat, Thanatchaya, Rattanaphorn, Nattapat, Angsana
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2.4.2 - How fungi and mold spread and factors that promote their growth	Nattapat	Napassarawadee
2.4.3 - Factors that limit mold and fungi growth	Nattapat	Napassarawadee
2.5 - Commonly used methods for mold minimization and prevention	—	—

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Glossary

Term	Definition
Adsorption	Attachment of molecules to a surface.
Annual rings	New cells in plants which are arranged in circles.
Biodegradation	Breaking down materials by microorganisms into products such as water and carbon dioxide.
Cellulose	Basic structural component in plant cell walls.
Depolymerization	Conversion of a polymer into monomers (smaller molecules).
Desorption	Process where an adsorbed substance is released from a surface.
Diffusion	Net movement of a substance from a region of high to low concentration.
Electronegativity	Ability of an atom to attract electrons towards itself when forming a chemical bond.
Equilibrium Moisture Content (EMC)	Moisture content of a substance that is neither gaining nor losing any moisture.

Fiber Saturation Point (M_f)	Point at which the cell walls of plant cells are filled with water (bound water) and the cell cavities are free of water.
Fungi	Spore-producing microorganisms which consume organic material. Includes mold, yeast, and mushrooms.
Hemicellulose	Another component of plant cell walls which binds to cellulose via hydrogen bonds.
Hygroscopic	Relating to humidity; retaining moisture.
Hypha (plural: hyphae)	Long, branching structure of a fungus.
Lethal concentration 50 (LC50)	The point estimate of the toxicant concentration that would be lethal and kill 50% of tested animals.
Lignin	Another component of plant cell walls which functions to give the plant stiffness.
Lumen (plural: lumina)	Hole in plant cells enclosed by a cell wall.
Modular design	A structure which is subdivided into many smaller parts called modules.
Mold	A type of fungus consisting of hyphae and occurring in moist, warm environments.

Mycelium	A network of fungal threads or hyphae.
Mycotoxins	A toxic metabolite produced by fungi that are capable of causing disease in both humans and animals.
Pits	Thin sections in plant cell walls.
Resin	A solid or semi-solid organic compound.
Rotting	The process by which dead organic matter is broken down into simpler substances.

Chapter 1 - Introduction

The Mrigadayavan Palace is a vacation residence that was built in 1924 for His Majesty King Vajiravudh (King Rama VI) and is located by the sea in Cha-am district, Phetchaburi (นายสด แดงเอียด, 1991). The Mrigadayavan Palace Foundation was created in 1992 under royal patronage to manage the conservation of the palace after the Fine Arts Department of Thailand designated the palace as a heritage monument in 1981. The foundation was established to preserve historical culture and sharing information about the history and heritage of the palace with the public. Because of this, the foundation is required to maintain the palace in its original form, both in structure and interior, as much as possible. The palace is situated next to the beach which, together with its beautiful historical heritage, has appealed to tourists. However, due to its location and the extensive use of teak wood for building main structures and walkways, the palace has been facing wood decay by molds and fungi for years.

A microscopic organism known as mold is a type of fungus ([M.C. Baker \(1969\)](#)). This organism comes naturally from the environment and can be found anywhere that moisture and oxygen are present. The way it obtains nutrients and its reproductive system sets it apart from all other living creatures. Like people, molds require food, water, air, and moderate temperatures to grow and survive. To develop and grow, molds require carbon and water, which they extract from the organisms they live on. There are two major effects caused by molds: the biodegradation of natural materials, and health concerns. For biodegradation of natural materials, the problems are food spoilage and damages to property. This is a major concern for residences made up of wood, as the mold is actively eating the wood and can cause serious structural damage over time. In addition, the growth of pathogenic molds inside the body, allergic sensitivity to mold spores, or the effects of ingesting or inhaling poisonous substances (mycotoxins) produced by molds are all possible causes of diseases in humans and animals.

In response to the problems that have been mentioned, the wooden buildings of the Mrigadayavan Palace have been affected by molds and fungi, and this issue has worsened over time. There have been previous BSAC-WPI projects that have contributed to the restoration over the years. For example, [ISSP BSAC \(2021\)](#) has identified viable preservation methods for rust corrosion and fungi deterioration in wood and concrete structures. In addition, ISSP-IQP (2022) has determined the causes of concrete disintegration and found

concrete rehabilitation methods. However, much is still unknown about molds and fungi and their effects on wooden buildings. Therefore, the foundation has been seeking ways that are efficient and avoid replacing the structures with new wood due to their historical conservation objectives.

We set out to investigate the wood-decaying issue at the Mrigadayavan Palace. We started by studying the mechanism of the wood-decaying processes and their prevention methods. To find suitable and practical solutions, our team has gathered information consisting of past restoration methods, wood composition, teak wood characteristics, wood degradation mechanism by molds and fungi, and how fungi and molds develop and reproduce.

The highest aim of our project is to understand the causes of the deterioration process of wood so that appropriate preventive actions can be selected to prevent further damage to the wooden buildings at the Mrigadayavan Palace. To accomplish this goal, the team proposed the following objectives:

1. Observe the structural damages and select the areas of study at the Mrigadayavan Palace.
2. Understand the wood deterioration process.
3. Understand how mold propagates on wooden buildings.
4. Find effective preventive actions for wood deterioration.
5. Provide a guideline booklet for wood deterioration to the Mrigadayavan Palace Foundation and people working at other old wooden buildings.

Chapter 2 - Literature Review

This chapter provides information on Mrigadayavan Palace, including its history, the design concept used, and past problems involving wood deterioration. It also details the properties of wood, teak wood, and factors that result in wood decay. In addition, it goes into detail about molds and fungi. Molds and fungi can be found anywhere that moisture and oxygen are present. To develop and grow, molds require carbon and water. There are two major effects caused by molds: the biodegradation of natural materials and health concerns.

2.1 - Mrigadayavan Palace

The Mrigadayavan Palace is a national heritage site opened by the Mrigadayavan Palace Foundation for preserving and maintaining historical culture. It allows people to visit and learn about its architectural, cultural, and environmental heritage and provide a case study for sustainable development and old building conservation. However, the palace is temporarily closed due to the recent COVID-19 outbreak. Thus, they used this time to focus on palace restoration and plan on reopening in 2024 for the 100th anniversary.

2.1.1 - History of Mrigadayavan Palace

Mrigadayavan Palace, located in Cha-am, Petchaburi, was the former home of King Vajiravudh (King Rama VI). “Mrigadayavan” means “park of deer”, which was suitable for the area since it used to have an abundance of hogs and deer. The palace complex comprised three main buildings. To the north was the Samosonsevakamataya Group of Buildings, which included a throne hall and a theater. In the middle, facing the sea, was the Samudabiman Group of Buildings, where King Rama VI resided with his trusted entourage member, Chao Phraya Ram Rakhob. To the south was the Bisalsagara Group of Buildings, the residence of Queen Indrasakdisajee. Long walkways separated the male and female servants, leading out to the sea, and there are row houses for attendants and servants.

His Majesty designed and supervised the construction himself (นายสด แดงเอียด (1991)). This was aided by Chao Phraya Yommarat (Pan Sukhum), Chancellor of the Ministry of Interior, as construction director, and Mr. Ercole Manfredi, an Italian architect in the royal court, Department of Public Works, who drafted the designs. Due to its modular

design, the palace construction took only a year, and His Majesty visited the royal residence twice in 1924 and 1925. His Majesty last stayed on June 20, 1925, after he returned to Bangkok, and passed away on November 25, 1925. Thus, the palace was abandoned until being officially registered as a national historic site by the Fine Arts Department in 1981, and the border patrol police started making renovations.

The structure of Mrigadayavan Palace was in bad condition after it was abandoned, being unused and uninhabited for more than 60 years. The surface of the wood had lost some of its paint, being exposed to rain, sunlight, and sea breezes, causing the teak wood to erode. Roofs with kite tiles had leaks and cracks, allowing raindrops to fall from the ceilings [\(ไทยโพสต์ \(2023\)\)](#).

The restoration was challenging, and there were several other issues. Around the buildings, countless thousands of wood pieces had been cut into segments, and the fretworks of the buildings had to be duplicated and reconstructed. Furthermore, the faded originals of the paintings on the ceilings had to be recreated. For over 13 years, the border patrol police repaired the palace, and it was finally reopened to the public on March 31, 1994, allowing everyone to enjoy once again the magnificence of the palace [\(ไทยโพสต์ \(2023\)\)](#).



Figure 1: Mrigadayavan Palace. [Source: Hua Hin Taxi \(2017\).](#)

The Mrigadayavan Palace Foundation was founded in 1992 to respect the wishes of King Vajiravudh and aims to conserve the historical and environmental heritage of King Rama VI ([Lakarnchua, I. \(2022\)](#)). The organization hopes to preserve the original structure of the palace with all the features still intact, including environmental and architectural aspects. Through continuous conservation efforts, they have successfully achieved their goal of maintaining the Mrigadayavan Palace.

2.1.2 - The modular design

The Mrigadayavan Palace was designed using the concept of modular design, where the structure has many joints, gaps, and connecting parts. This was to ensure the independence of each building and also to accelerate the construction of the palace ([Lakarnchua, I. \(2022\)](#)). The construction of the palace started in 1923 and was completed in 1924, only taking one year to complete due to the use of modular design, where the parts were already built when arriving at the construction site and the modules only needed to assemble together ([Triwat Viryasiri & Sakunjaroenpornchai, P. \(2018\)](#)).

For the palace, the walls and other parts of the buildings are made up of pieces of the same size, making the design very precise and uniform. In the horizontal dimension, the walls between columns are divided into seven equal parts, with each part measuring 40 cm. This means that the ratio of the aperture (openings such as doors and windows) to the enclosures (i.e., the solid parts of the walls) is 2:3:2 throughout the building. Thus, for every seven parts of the wall, two are for openings, three are for solid enclosures, and the remaining two are for more openings. In the vertical dimension, the rooms are generally three meters high, which is the same as the span of the walls. However, for certain functions that require more space, the height is expanded to six meters, or two spans. Each module has an opening for ventilation covers with a framework in the Art Deco style, giving coherence to the architecture and imparting unity to the whole structure ([Muangyai, N. \(2008\)](#)). This modular system ensures consistency and precision, with all the pieces fitting together perfectly.

2.2 - Problems of wood deterioration at the Mrigadayavan Palace

As the palace ages, the whole structure has faced the problem of deterioration in both concrete and wooden structures. During the past restorations, it was found that the builders were not sufficiently meticulous during the restoration process and used materials that were unsuitable for the old structures. For instance, heavier tiles were installed without regard for the weight-bearing capacity of the original beams. Consequently, the beams were unable to support the added weight, leading to structural problems. The builders also drove nails through the wood, exposing the interior to environmental elements, causing rust and accelerating wood decay. This disregard for appropriate construction techniques is a significant factor contributing to the deterioration of the structures in the buildings.

The Mrigadayavan Foundation has looked into the causes of deterioration that make the wooden structures decay. They want to understand the methods of wood restoration and preservation that do not result in further damage to old wood, whether it be the sanding of the surfaces to apply new coatings or the risks from using chemicals to remove the fungi. In addition, they want to reduce the need to replace the old wood to maintain its historical value.

2.2.1 - Past restorations

As the palace has been abandoned, the structure of the palace has been damaged and deteriorated due to neglect in maintenance, and the effect of weather (water, sunlight, wind, and salt spray). In addition, during its abandoned state, the palace was inhabited by people who caused further damage, modified and removed some original pieces from the original structures. With the palace being severely damaged, a major restoration was organized from 1983 to 1991 (นายสด แดงเอียด, 1991). The restoration included taking down the roofs and canopy parts to fix the main frame structures and selecting usable parts according to their conditions (e.g., still in one piece, no cracks, no change in color). The parts that could not be used were replaced with the same type and size of material. Also, cleaning, applying coatings that will withstand weathering conditions (e.g., shell drying to heal the wood before painting and weather coating for protection), and painting were carried out. They also added more nails to some areas to enhance the stability of the structures, fixed the concrete structures, and replaced the furniture and interior. In addition, the electric and water systems were also fixed.

2.3 - Wood

Wood is economically feasible and readily available, being one of the most widely used natural resources in the construction of furniture and houses. Wood is known for its strength-to-weight ratio and insulative properties, being easily shaped and sized to meet its application requirements. Additionally, wood is an environmentally sustainable material as it is biodegradable, renewable, and has the lowest carbon footprint of any comparable building material. Wood production does not require high-energy fossil fuels, unlike other building materials such as brick, steel, or plastic. It is essential to know wood's composition, causes of deterioration, and how water is transported through it.

2.3.1 - Wood composition

The appearance of the wood consists of annual rings. Upon further examination of wood on the nanometer scale, a network of porous microstructures with pits can be seen, which are pathways through cell walls that connect lumina (other pathways) of adjacent cells ([Thybring and Fredriksson \(2021\); Figure 3](#)).

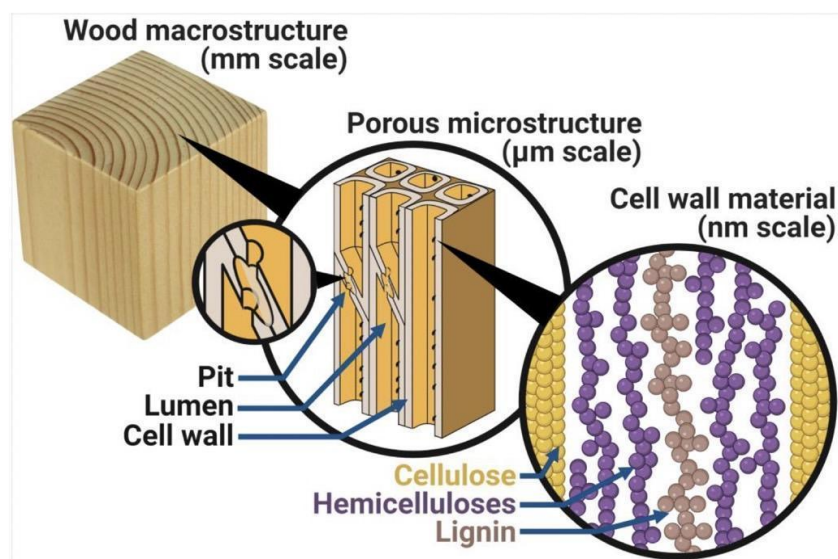


Figure 2: The structure of wood on a nanometer scale. [Source: Thybring and Fredriksson, \(2021\)](#)

Wood is a complex plant tissue composed of three principal polymeric chemical materials that make up cell walls: cellulose, hemicellulose, and lignin ([Haque, A. et al. \(2017\); Figure](#)

3). The skeletal substance is cellulose, which provides high tensile strength to complex wood structures. Hemicellulose serves as a temporary matrix before lignification, while lignin gives the tree stiffness so that it can grow upright. The central lamella is where it is concentrated, and this acts to bind individual cells together ([Kollmann, F., Cote, W. \(n.d\)](#)). Thus, understanding wood composition is vital to prevent damage to the wood structure when using chemicals and essential oils.

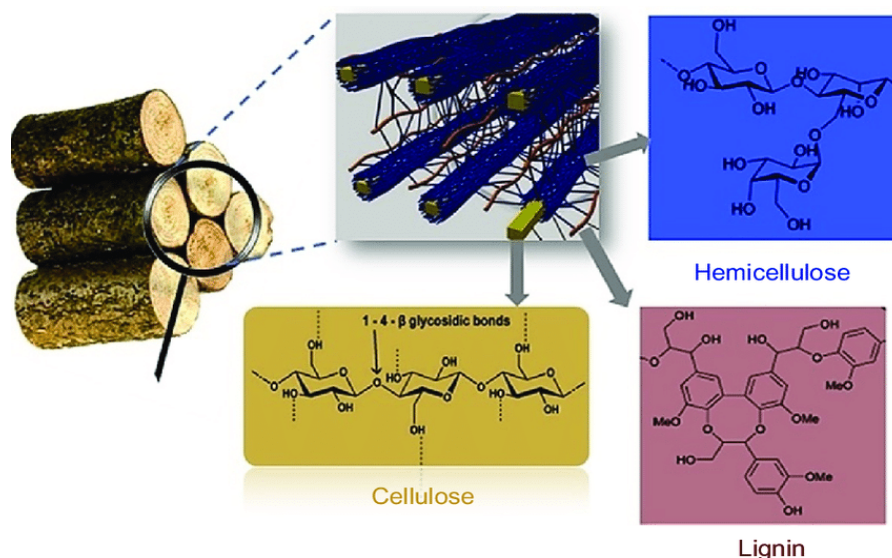


Figure 3: The structures of cellulose, hemicellulose, and lignin in wood. [Source: Haque, A. et al. \(2017\).](#)

2.3.2 - Teak wood

Teak (*Tectona grandis*) is a tropical hardwood and is considered to be the king of woods as it is highly desirable due to its many advantages. It is widely used in outdoor furniture due to its durability and beauty and can withstand exposure to water. Due to its adaptability, teak has emerged as one of the most popular lumbers in the contemporary woodworking industry and is also highly valued in Thailand ([Lampech, W. \(2020\)](#)). According to [Darmawan, W. et al. \(2019\)](#), a study was conducted to compare the benefits of teak, camphor, and pine woods. It was found that teak wood possessed considerable strength and resistance to natural weathering conditions, had a low cracking rate, and high durability compared to camphor and pine woods. Teak wood has a low fungal growth rate and has a long service life. Moreover, it is relatively easy to cut and its natural oils (resins) give teak the ability to resist moisture, termites, acids, and fungi, preventing it from decaying quickly. Teak can be easily bonded

and polished even though it contains a lot of natural oils, especially once the surface has been cleaned with a gentle solvent.

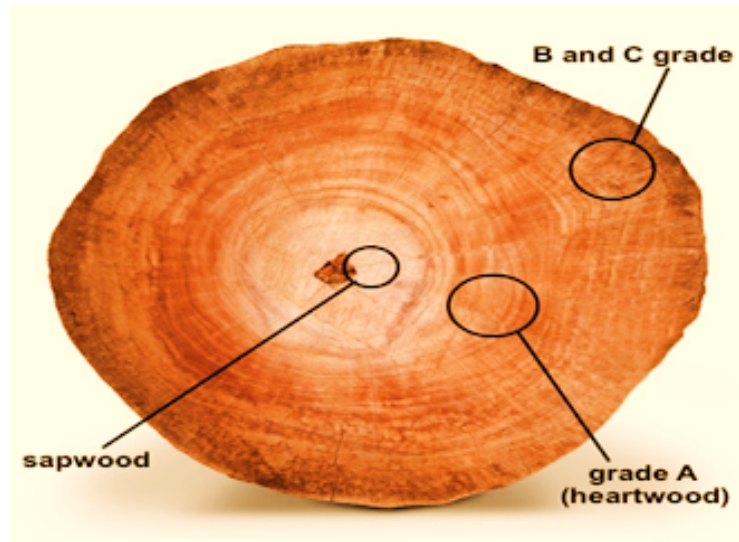


Figure 4: The structure of teak wood. [Source: LCETED.](#)

From Figure 4, teak wood is composed of two layers: sap wood (yellowish/white) and heartwood (golden brown/dark brown) ([LCETED \(n.d.\)](#); Figure 4). For the sapwood layer, it is a soft layer that is the active part of the wood where it uptakes nutrients from the roots to other parts of the tree. In contrast, the heartwood layer is clogged with resin and becomes harder to support the tree structure. Thus, teak wood resists termites and insects as the outer part of the wood is heartwood which condenses with teak resin, giving resistance properties ([Anre, A. \(2019\)\)](#). From the figure above, teak wood used for furniture materials can be separated into several grades (A-C) depending on which part of the wood has been used. Different grades differ in color, hardness, and durability, where grade A is the highest quality while grade C is the lowest quality ([LCETED \(n.d.\)](#)).

2.3.3 - The cause of wood decay

Wood decay is a consequence of the decomposition of wood tissue. It can result from various factors, including sunlight, water, wind, insects, fungi, and human influences ([M.C. Baker \(1969\)\)](#). The wood decay due to fungi and molds results from fungal infection combined with moisture and temperature. There are various types of wood decay, which have been named

based on the visual appearance of the wood material. Thus, significant research has been conducted on wood decay caused by fungi and molds and ways to prevent it.

2.3.4 - Wood-water relationship

Wood is a porous material that allows water to enter in three different ways: capillary action, vapor diffusion, and molecular diffusion ([PUU INFO \(2020\)](#)). Capillary action occurs when water is drawn into the cell lumens of the wood through the tension process. Similarly, vapor diffusion results when water vapor moves through the same cell lumens. Finally, molecular diffusion occurs when water molecules move through the cell walls of the wood. Wood can absorb water due to the hydroxyl groups (groups containing many water-attracting molecules consisting of a hydrogen atom and an oxygen atom) in the wood components (e.g., cellulose, hemicellulose, and lignin). These groups contain oxygen atoms covalently attached to hydrogen atoms, which are significant contributors to the properties of wood. Due to the high electronegativity of the oxygen atoms, the bonds of the hydrogen atoms and oxygen atoms are highly polar, which causes the hydroxyl groups to be strongly attracted to water molecules, thus creating hydrogen bonds (Figure 5).

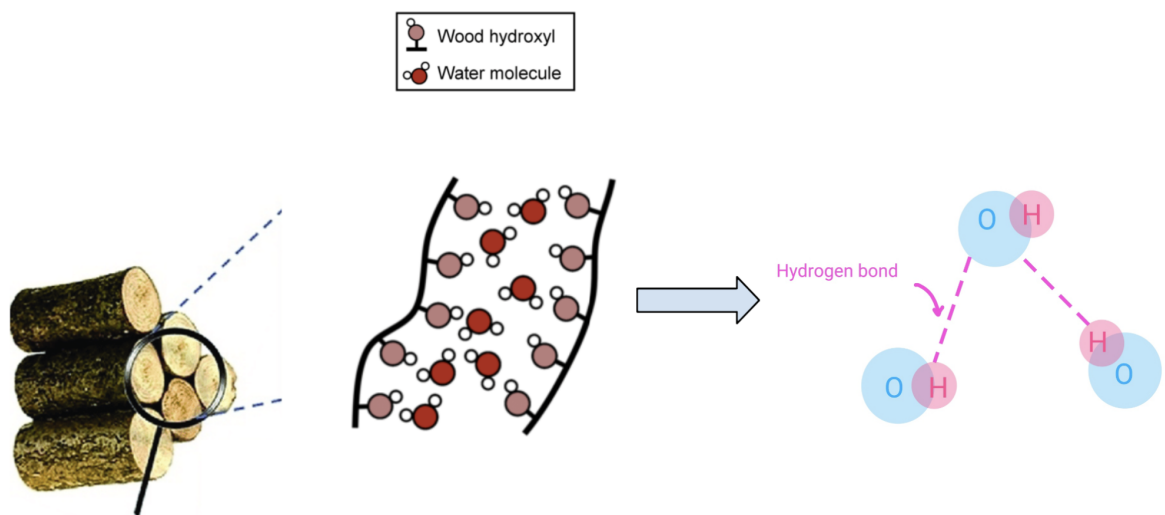


Figure 5: Hydrogen bonds between the hydroxyl groups of both wood and water. [Source: Thybring, E. E. \(2017\).](#)

The moisture content of wood is a measure of the amount of water in the wood, expressed as a percentage of the dry weight of the wood ([Brischke, C. & Alfredsen, G. \(2020\)](#)). For example, if a piece of wood weighing 100 kg contains 50 kg of water, the

moisture content would be 50%. This measurement is important because moisture content affects the strength, stability, and durability of wood products. In addition, it is also affected by the temperature and relative humidity of the surrounding air. As the moisture content changes, the wood may shrink, swell, crack, or experience internal stresses, which can cause problems for wood conservation. The physical and mechanical properties of wood-based products are also affected by moisture content. Additionally, the moisture content is critical for the development of biological degradation, as wood-degrading fungi require a minimum moisture content of 17% and an optimum range of 30% to 70%, depending on the fungi and wood type ([I. Hartley, M.F. Hamza \(2016\)](#)). Therefore, to prolong the survival of wood and wood-based products, an understanding of the nature of its water content and how it relates to the microstructures and properties of the wood is necessary.

There are two types of water in wood. The first is the 'water of constitution', which is inherent to the organic nature of the cell walls and cannot be removed without modifying the chemical composition of wood. The second type of water comes in three forms (Figure 6):

- 'Bound' or 'hygroscopic' water, which is adsorbed by sorption sites in amorphous areas of cellulose and hemicellulose present in the cell walls.
- 'Free' water, which is liquid-like water in the cell lumens and voids.
- 'Vapor' water, which is present in voids and cell lumens unless the wood is completely wood products saturated.

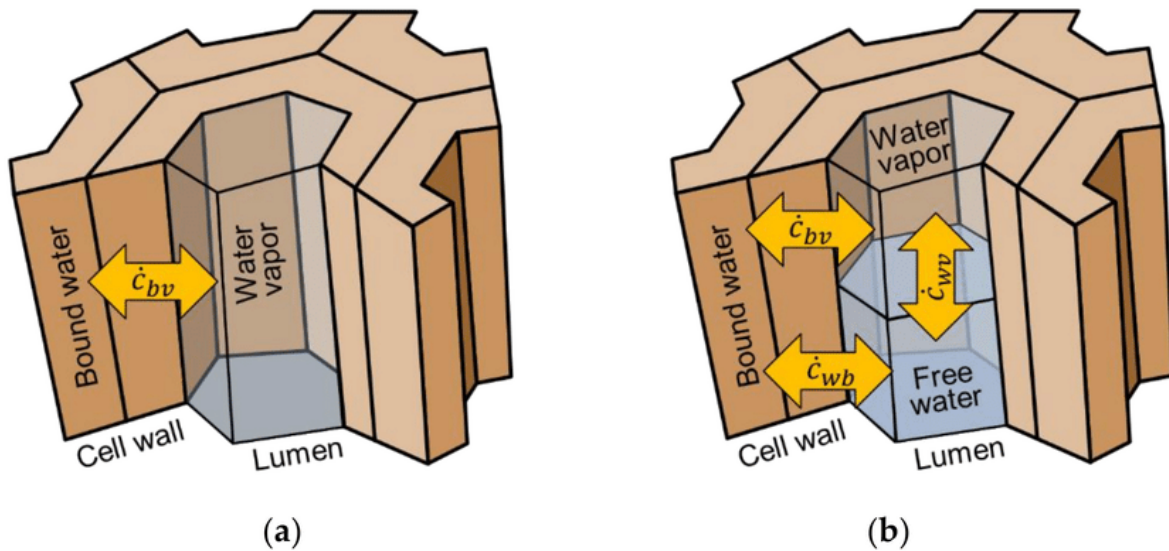


Figure 6: Different phases of water in wood. [Source: Fortino, S. \(2020\)](#)

When wood is exposed to the atmosphere, it begins to lose moisture. Initially, water leaves from the voids and cell lumens, while the bound water content remains constant. The moisture content level where the cell lumens contain no free water but still contains water vapor, and no bound water has been desorbed from the cell wall material, is called the fiber saturation point (M_f). For most temperate woods, the M_f is in the range of 25-30%, while it is lower for tropical woods that have higher extractive contents. As the moisture content of wood decreases below the M_f , bound water begins to leave the cell wall material. Most of the physical and mechanical properties of wood vary with moisture content below M_f . At a certain point, moisture in the wood reaches an equilibrium with that in the surrounding atmosphere. This is called the equilibrium moisture content (EMC), where the wood will not gain or lose any moisture with time.

2.3.5 - Temperature promotes growth of fungi and molds

Moderate temperature is the first condition for fungal growth, with an optimum range of around 24°C to 32°C. Growth essentially stops beyond the extremes of around 4°C and 40°C. Unfortunately, humans also live in the same temperature range as fungi, so regulating temperature is not a practical way to prevent fungal growth. However, temporary storage of wood in refrigerators or freezers is a highly effective (albeit expensive) way to prevent

deterioration, especially for green wood. Fungi also require oxygen to grow; for instance, waterlogged wood does not decay due to the absence of oxygen.

Approximately 20% air volume in the wood is necessary for fungal development. If green wood with high moisture content is kept from drying out, fungi can be controlled; however, this is not always possible. Moisture content is also a critical factor - the optimum level for fungal growth is at or slightly above the fiber saturation point (about 30% moisture content), in which the cell walls are saturated, but the cell cavities are essentially empty. Fungi can develop in wood with average moisture content as low as 20%. Drying wood quickly down to below 20% moisture content and keeping it dry is the primary way to prevent fungal deterioration. One of the main reasons for drying wood is to prevent fungi from developing.

Wood rots due to fungi growth under specific moisture and temperature conditions, not simply because it is wet. When fungi grow on wood tissue, it leads to the breakdown and complete dissolution of the wood substance, known as rotting. Understanding the types of wood rot and the conditions required for their growth is important. This knowledge can help modify the usage conditions of the wood or allow for treatments to prevent fungal growth from starting.

2.4 - Fungi and mold

Fungi and molds are microscopic organisms that can cause significant damage to various types of objects. They have been known to cause structural damage to buildings, degrade textiles and leather goods, and even cause health problems for humans and animals. It is essential to prevent and control the growth of fungi and molds to protect our belongings and ensure a safe living environment. This section details how they function and the factors that limit their growth.

2.4.1 - How fungi and mold function

Fungi and molds are natural decomposers that feed on sugar, starch, organic matter, and water. They are a type of microorganism with a great diversity of species and undergo rapid multiplication. When fungi grow on wooden surfaces, they destroy the wood cell wall components (cellulose, hemicellulose, and lignin) by releasing enzymes ([Haque, A. et al. \(2017\)\)](#). The enzymes that are responsible for the depolymerization of the carbohydrate components (e.g., cellulose) are hydrolytic enzymes (cellulase), which utilize water to break down the bonds of large molecules into smaller molecules. Another enzyme that fungi release is oxidative enzymes (laccase), which degrade lignin.

The decay caused by fungi can be categorized into two types: white rot and brown rot ([M.C. Baker. \(1969\)\)](#). For white rot, the fungi break down lignin and cellulose, which softens the wood and makes it feel moist, while the rotten part appears white or yellow as lignin responds to the brown color of the wood. As for brown rot, it primarily decays cellulose and hemicellulose in the wood, causing the wood to be brownish and break down into small pieces.

Mold is a type of fungus in the form of hyphae (multicellular strands). It is very small and only visible when it forms an interconnected network called mycelium ([Wet & Forget \(2018\)\)](#). It stains wood, breaking down wood structures by digesting the carbon atoms on the surface of the wood, causing an unpleasant odor. These hyphae strands spread to acquire more food sources as they exhaust the food and water in the current area.

2.4.2 - How fungi and mold spread and factors that promote their growth

Fungi spread by releasing spores into the air and disperse by wind and water, until they catch on the surface of a suitable medium such as wood and begin to germinate. The factors that promote the growth of fungi are temperature, water, oxygen, and food source (such as sugar and organic material) ([M.C. Baker. \(1969\)](#)). The main factors are water and moisture in the air and on wood. Fungi grow exceptionally well in humid environments as the enzymes that respond to decay need water to break down the components. As for the oxygen factor, they require oxygen to oxidize sugars (food), which they use for growth.

2.4.3 - Factors that limit mold and fungi growth

While some variables that encourage mold growth are necessary, their absence can also inhibit their growth. For instance, the lack of water can also prevent the growth of molds and fungi as they cannot function. Thus, some factors can limit the growth of mold and fungi on wooden surfaces.

Sunlight is one of the factors that limit the growth of molds on wood. It is composed of UV-C rays which can damage and destroy mold spores by disrupting the nuclei in the DNA of the microorganisms ([Jennifer \(2022\)](#)). When the DNA has been damaged, the mold cannot reproduce, thus causing the mold cells to die eventually. It takes one to three hours for the sunlight to damage the cells. However, this only affects the growth of molds and cannot remove the molds from the already infected wood, as the sunlight is in direct contact with the mold in which the cells are damaged. Hence, only the molds at the surface are affected, but not the molds that are inside the wood. In addition, the heat that radiates from the sunlight can evaporate the moisture in the contact area, thus reducing the area's humidity. Moreover, even though sunlight hinders mold growth, it is also one of the factors that cause the wood to deteriorate, as UV radiation damages and destroys the lignin of the wood.

Many chemicals that are used for fungicides are related to changing the pH of the environment of fungi and mold. Molds prefer to live in an environment with a low pH (around 3 to 7). Some chemicals are high in pH and have antifungal properties that can be

used to prevent and inhibit mold growth. Therefore, the factors that encourage mold growth need to be carefully considered to prevent or minimize these microorganisms' growth.

2.5 - Commonly used methods for mold minimization and prevention

There are various methods of prevention and minimization of fungi that have been studied to preserve wood. These methods are described below.

2.5.1 - Mold and fungi prevention methods

To prevent fungi and molds from growing on wood, wood finishes have been used to create a protective layer. These contain chemicals that prevent mold growth and prevent moisture from becoming trapped inside, which is one of the causes of mold reproduction. The palace has four types of wood finish: oils, paints, stains, and varnishes.

For paint, it can be separated into two types: oil-based paint and acrylic paint. Oil-based paints contain ground-colored pigments mixed with oils and various solvents depending on the paint type and quality ([Faessler, M., Faessler, T. \(2021\)](#)). The advantages are that they are highly durable, dry solid, and create a glossy finish. In addition, they are waterproof when dry. Because of this, they are suitable for both interior and exterior use. The disadvantages of oil-based paints are that it takes a long time to dry (six to eight hours), are considerably thicker than acrylic paints, and require a solvent to clean up afterward. Furthermore, the paint can become viscous if applied too quickly or densely. Oil-based paint is also poisonous and requires a mask and a ventilated area when handling them.

Acrylic paint consists of a water-soluble formula containing pigments in a polymer emulsion ([Faessler, M., Faessler, T. \(2021\)](#)). This type of paint can be used with a wide range of wood and has thus become increasingly widely used over the years. Acrylic paint has a low fungal growth rate and can protect teak wood for up to 36 months. The advantages of acrylic paint include a quick-drying time (30 minutes) and easy cleaning. In addition, they are non-toxic and safe for indoor use. They also have little odor and a low Volatile Organic Compound (VOC) amount. The disadvantages of acrylic paints are that they are easily chipped and have a lower gloss than oil-based paints.

Deck or wood stain is a type of paint consisting of pigments, solvents, and binders commonly used to color wood and inhibit discoloration. Deck staining protects from ultraviolet sun and moisture damage, helping maintain and improve wood appearance by highlighting its natural grain. A disadvantage of staining is that the wood requires re-staining more often and is less predictable than paint ([Dunbar Painting \(2019\)](#)).

Teak oil comprises linseed oil, pure tung, mineral spirits, and varnish and is suitable for exterior use ([Barron, J. \(2020\)](#)). It slows the aging process and resists rain, moisture, and humidity. Teak oil should be reapplied every six months to a year, depending on the dryness of the wood. It provides UV protection due to various pigments, absorbers, or filters. Teak oil absorbs UV light and prevents it from penetrating the wood surface, which can cause fading. It also has good weather resistance and tolerates wear and tear, but extreme weather conditions can damage the wood. A disadvantage of teak oil is its lack of waterproofing ability and poor water resistance.

Polyurethane is a varnish and synthetic microscopic chain of resin molecules that bond tightly with one another to form a protective layer as it dries. It is used for finishing wooden floors and gives the wood a glossy finish that is highly water, abrasion, and scratch-resistant ([Precision Urethane & Machine \(n.d.\)](#)). A disadvantage of polyurethane is that it has high water resistance and is not moisture-proof. It only protects the wood from water but not from moisture in the air. Since the coating may not be 100% tightly sealed, there may be gaps that allow moisture into the wood. Because the layer has high water resistance, the humidity inside of the wood cannot get out through small openings, thus resulting in the degradation of the wood.

In addition, other than using paints and finishes, physical methods have been used to prevent and minimize molds. These methods include dehumidifiers and air purifiers ([The Duct King \(n.d.\)](#)). The dehumidifier is beneficial as it helps decrease moisture levels to below 50%, thus preventing warm, humid areas from developing. Air purifier (HEPA air purifier) cleanses the air around the device and removes mold spores and other contaminants by passing them through a HEPA filter.

2.5.2 - Main substances for mold and fungi minimization

Chemical compounds can be used to reduce the growth of mold and fungi on wood, with the same chemical being able to function as an antimicrobial, fungicide, and disinfectant. Many chemicals are used as mold remedies, the most common ones being chlorine, hydrogen peroxide, quaternary ammonium compounds, and essential oils.

For chlorine products (such as bleach), they can be used to remove mold stains on hard surfaces; however, they cannot remove mold on porous surfaces, such as those in wood.

Only the surface of the wood can be cleaned with bleach, since the mold has spread deep inside the wood ([Vermes, K. \(2019\)](#)).

Hydrogen peroxide is also used to treat mold and fungi and is inexpensive and commonly found in stores. It releases oxygen rapidly when applied to the mold, causing the surface to oxidize and thus decompose ([The Mold Doctor \(n.d.\)](#)). It can be used on non-porous and porous surfaces like carpets or wood. The downside is that although hydrogen peroxide is said to remove mold, it does not necessarily kill mycotoxins. However, it does not generate toxic fumes or residues and is environmentally friendly, leaving no pollutants behind.

Essential oils and quaternary ammonium compounds are widely used for mold removal treatment. Quaternary ammonium compounds are popular as they are flexible - hundreds of different formulations are available. It is also considered low in toxicity and has a reasonable price. However, there are some downsides of quaternary ammonium compounds in that it can cause skin irritation upon prolonged contact. For essential oils, they are substances that are derived from plants and have inherent antimicrobial properties. This class of substances is popular as it is natural and does not harm the environment. The green chemicals include lemon, fruit extracts that contain citric acid, and essential oils ([Pinto, M.A. \(2020\)](#)).

2.5.3 - Wood modification for preservation

Wood surface modification is a process of improving the properties of wood to increase its value and prolong its life cycle, both indoors and outdoors ([Teacă, C. & Tanasă, E. \(2020\)](#)). There are several approaches to wood modification, including chemical, biological, mechanical, and physical methods. These methods enhance wood properties such as dimensional stability, durability, and mechanical strength. One approach is impregnation treatment, which involves the diffusion of bulking chemicals into the cell wall or lumen of the wood without changing its molecular structure. This results in increased wood density and resistance to water penetration. Another approach is coating modification, which involves applying a physical barrier layer of agents resistant to moisture, bio-degradation, fire, or UV radiation. This method is effective in protecting wood from weathering processes in exterior applications. There is a growing interest in using natural resources (such as resins, waxes, and

biopolymers) for wood treatment, as these alternatives can reduce costs and environmental risks at the end-of-life of treated wood.

In summary, wood surface modification is a crucial process for improving the properties of wood and increasing its value. Impregnation and coating treatments are common approaches that can enhance wood resistance to environmental factors. Using natural resources for wood treatment is a promising alternative for reducing costs and environmental risks.

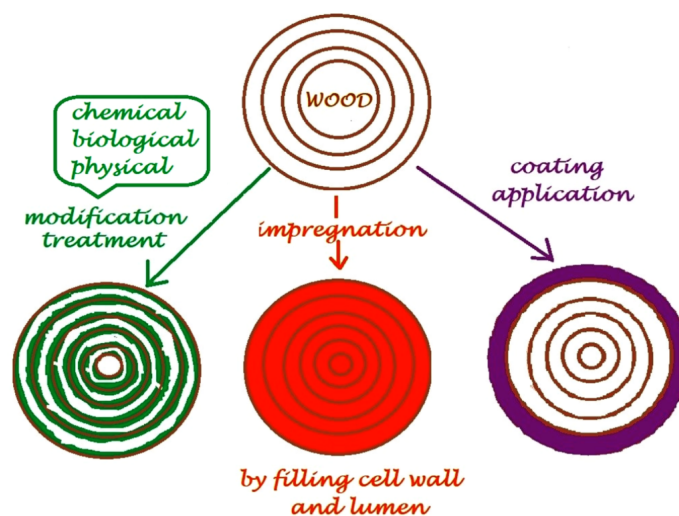


Figure 7: Wood modification options. Source: [\(Teacă, C. & Tanasă, F. \(2020\)\)](#).

2.5.4 - What has been done?

The prior methods and studies are crucial for a thorough grasp of how to avoid mold growth since they may give background knowledge and aid in determining the best approaches to the issue. According to the [ISSP BSAC \(2021\)](#), they have identified viable preservation methods for rust corrosion and fungi deterioration in wood and concrete structures. Moreover, apart from preserving them, they have also created a monitoring system for conserving the Mrigadayavan Palace. The outcome of this last project was creating a poster that illustrates the information about wood and concrete and a guide for the removal of fungi. They also used QR codes placed on the pillars of the palace walkways, so anyone that passed could scan the codes and understand the problems and methods of rust corrosion and

fungi deterioration. For the monitoring system, there was a form that recorded the date, time, and changes in the wood and concrete.

In addition, ISSP-IQP (2022) has determined the causes of concrete disintegration and found concrete rehabilitation methods. The results of this project were guidelines with a decision tree and a criteria table. In addition, they also provided educational content via a website to appeal to the younger generation. QR codes were also used for digital posters.

2.6 - Research gap

The Mrigadayavan Palace Foundation has had many contributions to the restoration progress over the years. Still, there is a need for skilled carpenters in works on restoration methods for old wooden buildings in Thailand. Typically, when the buildings experience wood decay, the owners simply replace the damaged parts. However, in the case of Mrigadayavan Palace, the foundation wants to maintain the structures and avoid replacing parts with new wood for historical conservation objectives. Furthermore, when researching mold prevention and minimization procedures, results are only obtained for indoor methods since molds mainly occur due to insufficient ventilation. However, there has yet to be much research on outdoor methods since the area is constantly exposed to air and sunlight.

Previous ISSP teams have looked at chemical means for removing molds and fungi. However, their methods were concluded to be ineffective because they needed to consider additional parameters (such as moisture). In addition, their main projects involved rust corrosion and concrete rehabilitation; therefore, not much is understood about the effects of molds and fungi on wooden buildings specifically.

To assist the Mrigadayavan Foundation, our team investigated the wood-decaying issues caused by molds and fungi, while founding methods and green solutions to protect the structures from further deterioration. We linked our knowledge together to create effective mold prevention methods. We aimed to provide proper wood protection and conservation guidelines to the Mrigadayavan Palace Foundation for their work on sustaining this historical and cultural heritage.

Chapter 3 – Methodology,

The goal of this project was to understand the causes of the deterioration process of wood so that appropriate preventive actions can be selected to prevent further damage to the wooden buildings at the Mrigadayavan Palace. To accomplish this goal, the team proposed the following objectives:

1. Observe the structural damages and select the areas of study at the Mrigadayavan Palace.
2. Understand the wood deterioration process.
3. Understand how mold propagates on wooden buildings.
4. Find effective preventive actions for wood deterioration.
5. Provide a guideline booklet for wood deterioration to the Mrigadayavan Palace Foundation and people working at other old wooden buildings.

1. Observe the structural damages and select the areas of study at the Mrigadayavan Palace.

To efficiently evaluate the problem of wood deterioration at the Mrigadayavan Palace and understand the cause of it, we qualitatively observed the areas of the palace where fungal growth and the breakdown of the wooden structure occurred. This was to assess the damage to the wooden parts of the palace and select the areas of study. In addition to the observation, we had discussions with the palace staff and current landscape architect to gain more information on the palace structure and areas that they were concerned about. Also, we had consultations with experts on mold and wood conservation to help in confirming the type of structural damage that occurred at the palace. The areas that we selected were areas B and J. The key difference between these two areas was their proximity to the sea - area B was located far from the sea, while area J was situated on the walkway near the sea. By studying and comparing the damage of these two areas, we could determine whether location affects the level of damage done to the building.

2. Understand the wood deterioration process

To gain a comprehensive understanding of the wood deterioration process at the palace, our team conducted thorough scientific research and a literature review. We also assessed the damages present at the site to determine whether weather, molds, or termites caused them. In addition, we interviewed the current landscape architect to gain a deeper understanding of the palace's structures and gathered case studies to aid in formulating effective strategies for tackling the issue. It was essential to note that wood deterioration can occur due to several factors; hence, by accumulating this information, the palace could address damages appropriately, thereby preventing them from recurring.

3. Understand how mold propagates on wooden buildings.

To evaluate how mold propagates efficiently, the team first considered the locations of the Mrigadayavan Palace near the coast, which contained high humidity levels. Interviews with the palace directors and staff were conducted to obtain insightful information about how molds spread and deteriorate wooden bugs. The questions asked during each palace visit are listed in Appendix C.

Furthermore, our team also investigated the possible parameters that caused mold propagation at the Mrigadayavan Palace to understand the factors that affect mold development and the rotting processes. This included studying the external factors such as moisture, weather patterns, and physical factors such as water leaks or types of wood replaced. By understanding the physical causes of mold propagation and assessing the deterioration of the area, we could help with the minimization of mold growth at the palace.

In addition, we interviewed mold experts, including professors at the faculty of botany and microbiology at Chulalongkorn University (Appendix D).

Lastly, we examined case studies of mold growth that have similar problems to the Mrigadayavan Palace. This included places such as the Sanctuary of Truth, a museum similar to the palace in that the buildings are constructed from wood and located near the sea.

After gathering all this information, we determined the causes of mold propagation on wood at the Mrigadayavan Palace and examined methods that could help our sponsor.

4. Find effective preventive actions for wood deterioration

In order to find effective preventive actions for wood deterioration, we have searched for mold minimization chemicals for old wooden buildings with regard to information and analysis methods. The team studied more research documents and also interviewed m to determine which substances were suitable and effective in minimizing wood deterioration. When providing or preventing wood deterioration, it was crucial to consider their effectiveness in reducing mold growth. This included factors such as the time and effort required for preparation and application, methods that were able to inhibit the occurrence of molds as long as possible, affordability, and ease of use for the end-users. Given the current staff shortage at the Mrigadayavan Palace, it was particularly important to identify methods that required less application. Our team conducted thorough reviews of scientific papers and case studies, which included both traditional methods previously used by the Mrigadayavan Palace staff, new methods, and also greener alternative methods. Furthermore, our team conducted an experiment to test whether the chemicals can remain in the wood long enough to stop the mold from regrowing on wood. This was to find which chemicals could remove molds and consider the time it takes for molds to redevelop on the wood. The experimental procedures came from our research and with the help of a mold expert professor (Ajarn Jittra Piapukiew). The experiment is provided in the last chapter of the guidelines book and Appendix H of the report and includes all information on chemicals that our team has researched, comparing each chemical that has the potential to eliminate molds on wooden surfaces for the Mrigadayavan Palace Foundation to consider.

Another preventive action is to provide mold prevention methods for wood with regard to interviews and observations. The team did background research and interviewed wood conservation experts. In addition, we observed places with similar conditions to the Mrigadayavan Palace (such as construction, weathering, and environmental conditions) and interviewed the people there about suitable mold prevention methods.

Thus, we considered the efficiency of preventing wood deterioration, which included affordability and the frequency of application. The prevention methods include preventing wood deterioration both in the short term and from future damage from either living or nonliving factors.. After considering the methods that are useful, the methods are added to the guideline booklets and recommendations.

5. Provide a guideline booklet for wood deterioration to the Mrigadayavan Palace Foundation and people working at other old wooden buildings.

In response to the wishes of the Mrigadayavan Palace Foundation to gain more understanding regarding the issues and the methods they have used for wood protection, our team has summarized our findings (including literature reviews, sponsor and expert interviews, and observations at the Mrigadayavan Palace) to create a guideline booklet. The information we gathered was compiled and reviewed to find methods for preserving the Mrigadayavan Palace to prevent wood deterioration. Afterward, the team listed all of these methods and constructed a guideline booklet on when, where, and how to implement these methods. This included when to reapply substances and the methods for areas affected by molds and fungi. The final format of the guidelines was a physical booklet and an online eBook. The team also provided infographics for these methods in digital posters, allowing people to scan the QR codes and learn more about how molds and fungi affect wooden buildings.

Furthermore, there was a section about experimental protocols for the team to experiment with the Mrigadayavan Palace along with their staff to test and compare the effectiveness of the mold-minimizing chemicals for future research. The protocols included the experimental procedures, how to monitor the results, and the criteria that indicated the effectiveness of the chemicals. In addition, we provided a monitoring form for the palace staff to continue monitoring the results to know which mold-minimization chemicals will be suitable for their conditions. All the experimental information and monitoring forms can be found in Appendix H. Also, we should have included paint brands in this experiment due to the specific shade of color required for the buildings at the palace. Consequently, searching for paints to test may yield the shade used. Thus, methods to prevent mold growth and wooden building deterioration were provided instead of conducting experiments on paints.

After we have created the guidelines and experimental protocols, they can be used by the Mrigadayavan staff members to find suitable methods for specific problems. The guidelines taught the staff members how to maintain wooden buildings and prevent molds from developing, not just inside the palace but also on any wooden structure or other historical buildings. With this knowledge, they could teach future staff members how to protect and care for the palace properly.

Chapter 4 - Results and Analysis

In this chapter, results from the data collected at the Mrigadayavan Palace and expert interviews have been reported. Our team has collected numerous pieces of information resulting in many findings, ranging from what we examined at the palace to new substances that were found to eliminate molds. The findings are detailed in the following chapter.

Finding 1: Observe the structural damage.

Our team observed the areas of the Mrigadayavan Palace that the staff had concerns about. Mapping out the sites using the floor plan provided by the staff, we selected the areas that were most concerning and should be focused on, which we concluded were areas B and J.

From our qualitative observation, we have found five types of damage to the wood that was visible in the selected area: peeling off of paint, cracks, and rots in the wood, and fungi and mold growing on the wood.

Finding 1.1: The area that was affected by wood deterioration the most was the canopy area.

We have found that the area of the palace that has the most structural damage was the wooden canopy area. The canopy is a part of the building that constantly faces weather conditions (e.g., rain, wind, sunlight). The site was very decayed and required immediate action to prevent the whole structure from collapsing. Also, black molds were spotted all over the area, and some fungi grew in zone B. The areas are illustrated in Figure 8.

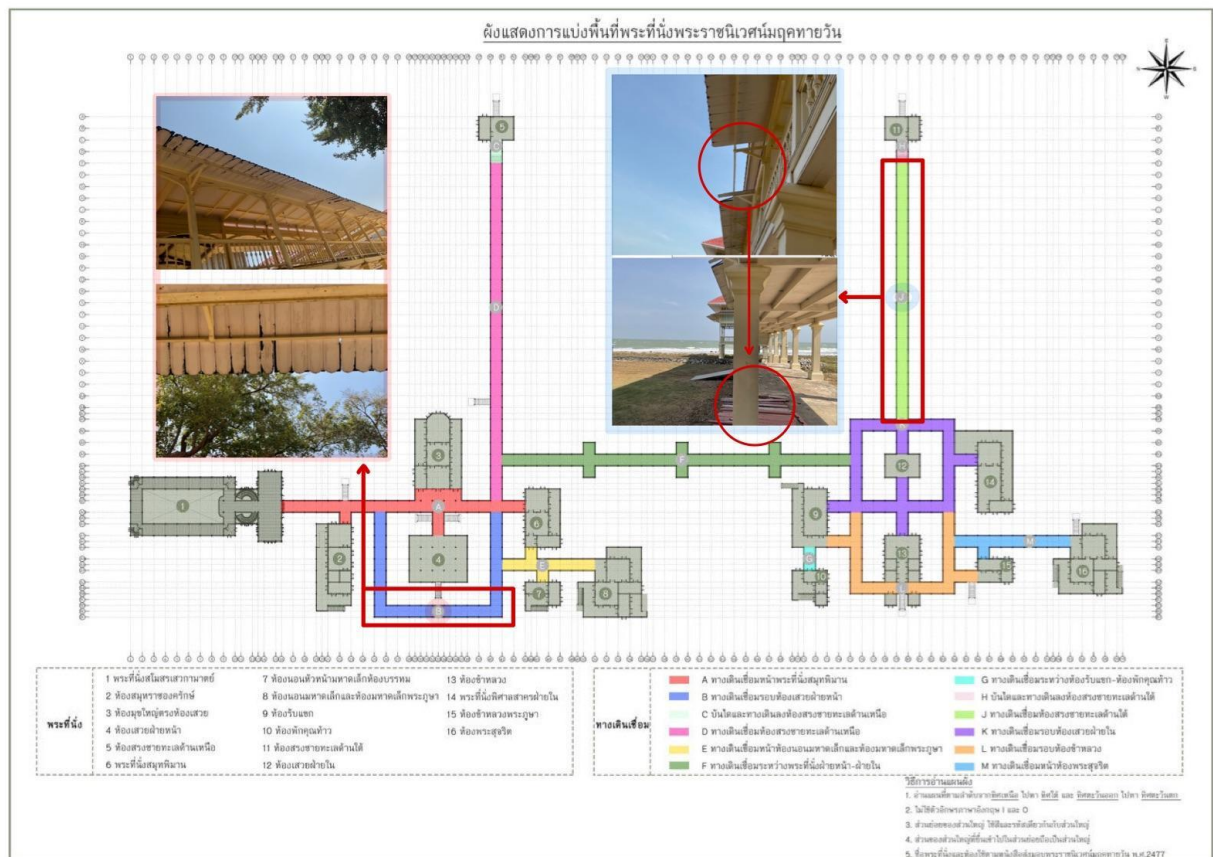


Figure 8: Map of Mrigadayavan Palace showing areas most affected by wood deterioration.

Molds and fungi have been a recurring problem as they have already penetrated wooden structures. Figure 9 shows that the mold has spread to significant parts of the canopy, even in the cracks. After examining the result of a lab test done by the Mrigadayavan Palace to identify species of molds, it was concluded by looking at their appearances that many of these species were brown rot (รายงานเชื้อรา พระราชวังเวศน์มฤคทายวัน, 2022). In addition, many pieces of the canopy have crumbled to pieces.



Figure 9: Pieces of the canopy with mold growth, causing them to decay (Location: Zone B).
(a) Small holes can be seen between the gaps in the wood panels. (b) Detached sections of

wood. The wood has decayed so much that some pieces have fallen off the canopy. (c) Image of wood used in the palace canopy decayed by mold.

Finding 1.2 - Types of damages to canopy areas.

The observation results show that every piece of wood on the canopy of the Mrigadayavan Palace was affected by black molds and moisture. There are three types of damage to the canopy. First, sections of the detached canopy from the roof (Figure 9(b)). Second, more than half of the wooden boards were damaged. Lastly, there were areas on the canopy with rotten edges (Figure 9(c)). To summarize, the canopy of the Mrigadayavan Palace was in poor condition due to black mold and moisture, which caused significant damage to the wooden structures. The damage can be categorized into three types: detached sections, high wood breakage rates, and areas with rotten edges.

Finding 1.3: Comparing two selected areas of study.

From the two areas that we have selected (areas B and J), we can see that the level of damage to the canopies was different. One can see that the canopies in area B suffered less damage than the ones in area J. Besides the differences in moisture due to different distances from the sea, we have also examined the path of sunlight at both locations during the year. We found that for area J, the canopies were exposed to sunlight from morning (sunrise at 7:00) until sunset (18:00). In contrast, those of area B were only exposed to sunlight during the afternoon period until sunset (12:00 - 18:00). The sun's path can be seen in the diagram in Appendix A. Therefore, according to the background information regarding the effect of the sunlight, we can confirm that sunlight is one of the reasons why the canopies in area J suffered more damage than those in area B.

Finding 2: Molds and fungi were not the only factors that caused wood deterioration.

From the observations, expert interviews (such as experienced architects and wood conservation and fungi experts), discussions with the palace staff, and additional literature research, we have found that fungal decay was not the only major cause of wood decay at the

palace, as the level of damage done to the canopy was too much for the fungi to do alone. The other two factors which affected wood deterioration were sunlight and moisture.

During an interview with Ruen Urai, an old wooden house in Bangkok, we observed that despite the absence of mold and fungi problems. This was evident by changes in color, roughness, and cracking, all of which are typical wood weathering effects. Upon further investigation, it was discovered that the deterioration could be attributed to sunlight exposure. When the protective paint layer on the wood peels off, the ultraviolet (UV) radiation can break down the lignin in the wood, leading to its degradation. This finding is supported by scientific research on wood weathering.

We interviewed an architect who is an expert on restoring wooden houses, Dr. Yuwarat Hemasilpin. She informed us that the problem of wood decay is a collective result of accumulated moisture, causing the wood to swell, and was aided by strong winds which spread the fungi spores and salt from the sea. As mold and fungi are organisms that need nutrients and water, the water that accumulated in the wood is the root source of the problem.

For the accumulated moisture in the wooden canopy, we first looked into how the canopy was constructed and assembled. It was designed using the modular design concept, in which the structures have many joints and gaps (refer to section 2.1.2; Figure 10). This resulted in water being trapped inside the structure as there are many connecting parts. As the palace is located near the sea, the moisture in the air and the salt spray were sources of moisture in the wood. When salt enters the wood, it absorbs water and penetrates the wood surface. Moreover, the areas around the palace contained many trees. The leaves fell into the gaps between the joints of the canopy; once trapped there, they released moisture that was still found inside and caused water to be trapped in the canopy structure, eventually leading to wood degradation (Figure 11).

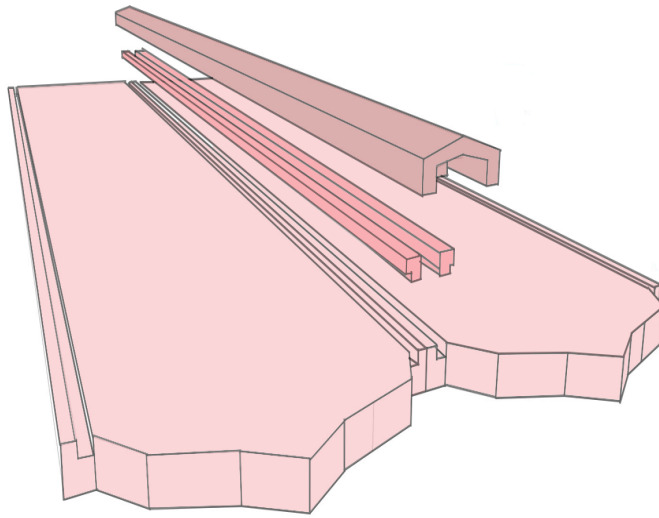


Figure 10: The modular design of the Mrigadayavan Palace. The system has many joints and gaps which fit together uniformly.



Figure 11: Traces of pine tree leaves left in the joints of the canopy can be seen in the wood.

Finding 3: The lack of staff limits the monitoring of damages and methods for preventing and minimizing wood decay.

The recurring problem of wood decay has also resulted from the lack of constant care. As moisture and fungi are the major causes of deterioration of the canopy, to minimize the problems, the area needs constant and thorough cleaning of fungi and molds, drying, and recoating of the wood (confirmed from our on-site observations). The neglect in maintenance will cause the wood to accumulate a lot of moisture and consequently cause it to swell, creating a suitable environment for fungi and mold to grow as it acts as a water source for these natural decomposers to feed on.

This problem is because the palace, which once was a tourist site, has been temporarily closed down during the COVID-19 outbreak in 2020. Many of the staff have left, leaving the palace with only two workers for cleaning and monitoring. As a result, there are not enough people to clean the area, eventually leading to the appearance of molds.

Moreover, from the observations along with interviews with the palace staff, the canopy is the area that was left out only until there was a big cleaning. Wet wood and moldy wood were left because, according to palace staff, if they wanted to do constant monitoring and cleaning, they would need to set the scaffolding and leave it there all the time since it is hard to assemble. Furthermore, because the palace was open to tourists, the scaffolding obstructed the beauty of the buildings, so it had to be taken down.

A previous ISSP team ([ISSP BSAC \(2021\)\)](#) has mentioned the use of wood drying techniques using an oven; however, we found that this method could be more efficient as the canopy was constantly exposed to humidity. Thus, comparing the long time it takes for oven-drying to be accomplished and the time the wood will become wet again, we have concluded that this technique is incompatible with the palace wood. As such, to help minimize the damage, using paints and other coatings was the most effective way to prevent the wood from moisture and molds. However, the method of oven-drying may still be used for the future replacement of damaged pieces.

Finding 4: Chemicals that are ineffective in eliminating molds and chemicals that may not be suitable for the palace.

From our findings, there were some chemicals that we thought would work to minimize molds but were proven to be ineffective. Our team has looked into a report from a previous ISSP project suggesting two methods to the Mrigadayavan Palace staff for removing fungi, which are Dettol and sodium hypochlorite ([ISSP BSAC \(2021\)\)](#). From our interviews with the Mrigadayavan staff member, they informed us that Dettol and sodium hypochlorite were ineffective in killing molds. Our team then wanted to understand more about how these past methods did not work, so we consulted Ajarn Jittra Piaphukeow, an expert on molds from the Department of Botany, Chulalongkorn University. She explained that Dettol is an antiseptic solution that kills bacteria and protects against germs, but it does not kill molds. Sodium hypochlorite is effective on non-porous surfaces, but as it is mixed with water, the water gets absorbed and creates moisture inside the wood. We also looked into more powerful chemicals, such as didecyldimethylammonium chloride (DDAC). This product is recommended for killing molds but is difficult to obtain as it is available only in large barrels. In addition, it is very toxic, so some of these chemicals require an expert or people with experience to apply them. Also, because these chemicals are considered harmful, they might not work in a place prioritizing conservation.

Finding 5: The need to specify the particular mold and fungi species was unnecessary, since fungicides are effective on most species.

As the palace has concerns over the types of fungi growing on the palace wood, there have been attempts to identify them. However, due to the nature of these microorganisms, there are over 200 species within the palace. To identify these fungi and molds, the palace must pay the microbiologists identification fees. This is expensive as to identify one species, it costs up to 1,000 baht per species, not including the cost to collect and prepare the samples (รายงานเชื้อรา พระราชานิเวศน์มฤคทายวัน (2022)). However, from the interviews with Ajan Jittra and Ajarn Panan, both have suggested no need to focus on identifying the species if the palace wants to minimize these fungi and molds. Nowadays, fungicides have been designed to work with most species of fungi and molds. Thus, when considering the efficiency of the need to identify the species of mold and fungi, it is not worth the money and time. Instead, it

should be spent on finding effective fungicides or chemicals that would work for all fungi and mold while damaging the wood as little as possible.

Finding 6: Chemicals that have the potential to eliminate molds.

Some chemicals have the potential to eliminate molds on wooden structures. In our interview with Ajarn Jittra, she recommended many chemicals that work to kill molds and also explained which chemicals to avoid. The chemicals that she suggested were distilled vinegar, borax, and hydrogen peroxide 3%. We then looked into more detail about these chemicals and how to apply them on wood. From our research, these chemicals could kill molds, and some even worked on porous surfaces. Ajarn Jittra also told us that many mold removal products in the market have different intensities on killing molds and that some products might be effective in some types of molds but not others. Nevertheless, all of the chemicals she mentioned had the potential to kill molds. For example, hydrogen peroxide destroys proteins in molds and can prevent the production of cell walls. Thus, our team also looked into more chemicals, including chlorine dioxide, iodophor, and benzalkonium chloride.

Chlorine dioxide is a substance that can potentially eliminate molds and is used in hospitals and food processing facilities as a potent disinfectant ([Elgazar, R. and Kemper, J. \(n.d.\)](#)). Chlorine dioxide is also part of the vital oxide substances used for hospital disinfectant cleaners and mold killers. Vital oxide does not have any harsh chemicals in it and does not irritate the skin. Both porous and non-porous surfaces, including carpet, concrete, and wood, can be utilized with this product. In addition, this product can also prevent mold re-growth for up to seven months ([Vital Oxide \(2022\)](#)). However, this product is unavailable in Thailand and requires shipping from other countries.

Iodophor is composed of iodine combined with a substance that helps it dissolve, making it used as a disinfectant. Iodophor also penetrates the cell walls and membranes of mold cells, which makes it effective in eliminating molds ([More Beer! \(n.d.\)](#)).

Benzalkonium chloride is a type of Quaternary ammonium compound (QAC), a disinfectant found in many detergents and odorless antiseptic compounds. In low concentrations, it kills bacteria and fungi ([Cameo \(n.d.\)](#)). A chlorine-free mold remover that

contains benzalkonium chloride can kill molds. This substance is not entirely dangerous; however, thorough ventilation and careful rinsing with clean water after use are required.

Finding 7: New alternative methods.

From attending the Conservation and Carpentry Fair, we listened to Associate Professor Dr. Panipa Chaowana from Petrochemical and Polymer Science, Wilailuk University. She gave a review about the non-toxic technology to protect wood which is involved with the water, which is one of the main factors that causes mold growth. Thus, there is a new technology that makes use of an alternative treatment approach. The first method is acetylation. The hydroxyl groups in wood absorb and release water, converting the free hydroxyls into acetyl groups using the acetylation method ([Vaisala \(n.d.\)](#); Figure 12). This will make the wood absorb and release less water. This is accomplished by reacting the wood with acetic anhydride derived from the common name of vinegar, acetic acid.

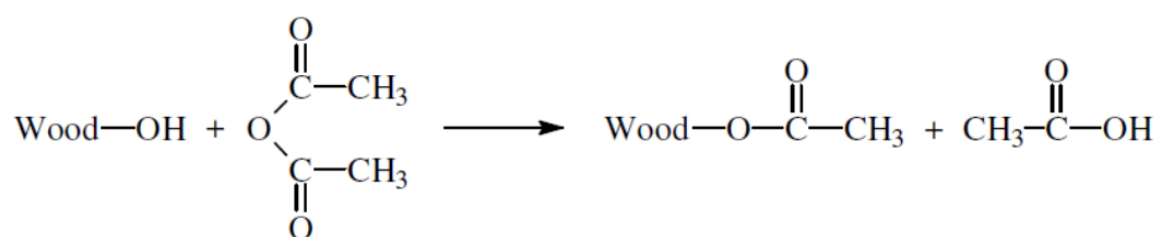


Figure 12: Reaction of hydroxyl group in wood cell walls with acetic anhydride ([Source: Teng, T. K. et al. \(2018\)\)](#).

For the thermal treatment, the hydroxyl group, which is active with water molecules, can be degraded by using heat treatment for the temperature range 180-250°C, which results in the wood absorbing less water ([Teng, T. K. et al. \(2018\)\)](#).

Applying resin to the wood is another technique that can aid in protecting the wood. In the filling procedure, formaldehyde resin diffuses into the cell wall to interact with up to two hydroxyl groups, creating cross-links between the hydroxyl groups on either side of the

reaction. The cross-links created by formaldehyde treatments may also prevent the cell wall from swelling

The lumina filling resin treatment is another way to apply resin to the wood. The majority of researchers have assumed that resin fills wood by penetrating the cell lumina, affecting its capacity to absorb water by obstructing the water-holding space. However, these methods fill up melamine resin into the cell lumen of the wood structure ([Awais, M. et al. \(2022\)\)](#).

The final technique uses nanotechnology and involves mixing a coating with nano-based materials like titanium oxide, which is frequently used in many coating products with the ability to shield wood from UV and water ([Xiaomeng, Z. et al. \(2022\)\)](#).

Finding 8: Green alternatives may not be as effective as expected.

Some of the well-known mold treatment solutions contain toxic compounds that can be harmful to one's health; therefore, green alternatives are provided by non-toxic chemicals ([EPA \(n.d.\)\)](#). However, some of these green chemicals are ineffective and unsuitable for mold prevention and minimization, especially in the canopy area constantly in direct contact with sunlight, rain, and moisture. The green chemicals include lemon, fruit extracts that contain citric acid, and essential oils.

Firstly, lemon is a natural, local Thai herb commonly found and also a water-soluble substance but is inefficient in preventing molds. This is similar to fruit extracts containing citric acid (e.g., citrus, grapefruits, mandarins, oranges). These are also water-soluble and each kind of fruit affects different types of molds. Lastly, essential oils (e.g. clove, eucalyptus, lavender, and especially tea tree oil) have antimicrobial properties that can kill mold and fungal spores ([Colorado Property Group \(n.d.\)\)](#). Each essential oil will be more effective on different types of molds. Eugenol is the main component of clove oil that damages the fungal cell membranes and inhibits germ tube formation. However, they could be more effective on molds if used as a dehumidifier or on indoor surfaces.

To conclude, most green chemicals are mainly ineffective because of their water-soluble properties, which are unsuitable to apply on the canopy area in contact with

rain and humidity. Moreover, many of them are not effective in killing molds because of the mild substances that are unable to destroy the spores of the mold underneath the surface.⁵

Finding 9: Epoxy can be used to block the holes in porous areas and repair the wood.

From the interviews with the palace staff, they have shown an interest in using epoxy to repair the wood back to its original shape. After we looked into more information and consulted with a conservation expert (Professor Craig Deller), we found that this method is indeed possible for the palace. Epoxy has the properties of high strength and waterproofing ability as it is made up of resins and hardeners that bond together to create a hard plastic that can be poured over wood.

Therefore, using epoxy can help block the porous areas of wood (such as gaps between the joints due to the modular design) and repair the holes and cracks in the wood. This will prevent moisture from entering the wood, accelerate the process of wood deterioration, and restore the appearance of the wooden part closer to its original state as much as possible. In addition, if proper maintenance is performed, epoxy can last up to 20 years. However, this method currently has some limitations and needs further study about the chemicals that will be used with the epoxy to make it stick to the wood at the palace.

Finding 10: Wood preservation processes

The manual (การป้องกันรักษาเนื้อไม้ (*Wood Preservation*)) was given to the team by the manager of the Sanctuary of Truth (Figure 13). The document includes six main chapters of essential and helpful information about wood protection. The first chapter explains the three main factors of wood protection: wood-destroying agents (e.g., mold), the natural durability of wood, and the protection processes. The second chapter is about the wood preservation process, which has two main types: pressure and non-pressure.



Figure 13: The Sanctuary of Truth, Pattaya.

The Sanctuary of Truth uses the pressure process, which prolongs the wood's lifespan. The pressure processes are divided into two main groups: full-cell and empty-cell methods. Both require an impregnating tank (owned by the Sanctuary of Truth; Figure 14) to impregnate wood preservatives through the wood cells deeper and more evenly than non-pressure processes.



Figure 14: The impregnating tank at the Sanctuary of Truth. The tank uses the pressure process to prolong the lifespan of the wood.

Finding 11: Results of testing the Filmprotector product

Filmprotector, an applicable film developed by Dr. Napida Hinchiranan that peels off substances on its surface, was found to be not very effective in removing molds from wood after the experiment was conducted. This was because of the long time required to apply the chemical to the wood and the time needed to peel it off, which is less efficient than using a clean rag and wiping off the molds. Also, the Filmprotector product needed to be stronger to pull out all the molds from the wood. However, a benefit of this product is that it can clean the surface of the wood well; in the case of our experiment, dirty spots on polyurethane coating that was difficult to remove had been cleaned off while the film did not peel off the layer. In addition, it can go inside the gaps between the joints, thus helping to clean the usually hard-to-clean parts. However, this result was insufficient to conclude the effectiveness of removing molds. This is due to the time limit for experimenting (1 hour), and the results may change with future attempts.

Summary

From the findings, we have concluded that the source of molds and wood decay at the Mrigadayavan Palace was due to the accumulation of moisture and sunlight from various sources. In addition, chemicals, green solutions, and paints were examined, concluding that some were ineffective and others were potentially effective in minimizing and eliminating molds. Thus, guideline recommendations are provided to the Mrigadayavan Palace Foundation for appropriate solutions to different situations.

Chapter 5 - Recommendations and Conclusion

This section consists of the guideline recommendations from our team to the Mrigadayavan Palace Foundation and historical wooden buildings for the mold and wood decay issues based on our results and analysis. It contains a set of recommendations for minimizing and preventing the growth of molds and fungi, wood preparation, using epoxy for porous surfaces, and conducting an experiment.

1. Recommendations for minimizing the growth of molds and fungi

Some effective chemicals can eliminate molds. To find suitable chemicals for mold minimization, each chemical that our team found was put into the criteria table (Appendix B). After we have selected chemicals by comparing their advantages, disadvantages, toxicity, and cost-effectiveness, we have recommended two chemicals to use to the Mrigadayavan Palace staff: borax and quaternary ammonium compounds (Benzalkonium Chloride or BKC).

Borax is a white powder derived from boron. Because mold prefers to live in an environment with a low pH level (between 3 and 7), the pH level of borax is 9.3, thus making it a very effective mold remover. When borax is used to remove molds from surfaces, it kills mold spores, inhibiting the growth of molds and creating an environment that is difficult for mold to survive ([Jennifer \(2019\)](#)). In addition, quaternary ammonium compounds (such as benzalkonium chloride) are well-known antiseptics that work well against bacteria and also with molds. Many mold remedy products have mixed benzalkonium chloride because of its adequacy in removing molds at low concentrations. It was used to eradicate lichens, algae, bacteria, and fungi. Thus, both of these chemicals are effective, and there is a product that we recommend use, which was developed by a start-up company called Alpha Innovist, along with Assistant Professor Dr. Rojrit Rojanathanes from the Faculty of Science, Chulalongkorn University. Borax and benzalkonium chloride are the two key ingredients in this product. Although it is currently in the prototype stage, this product has been tested in the laboratory and has shown that it can get rid of mold. There are two prototypes: MDP01 and BSAC 14. The BSAC14 formula combines benzalkonium chloride with borax and a booster (activator); while MDP01 formula combines benzalkonium chloride with enriched borax.

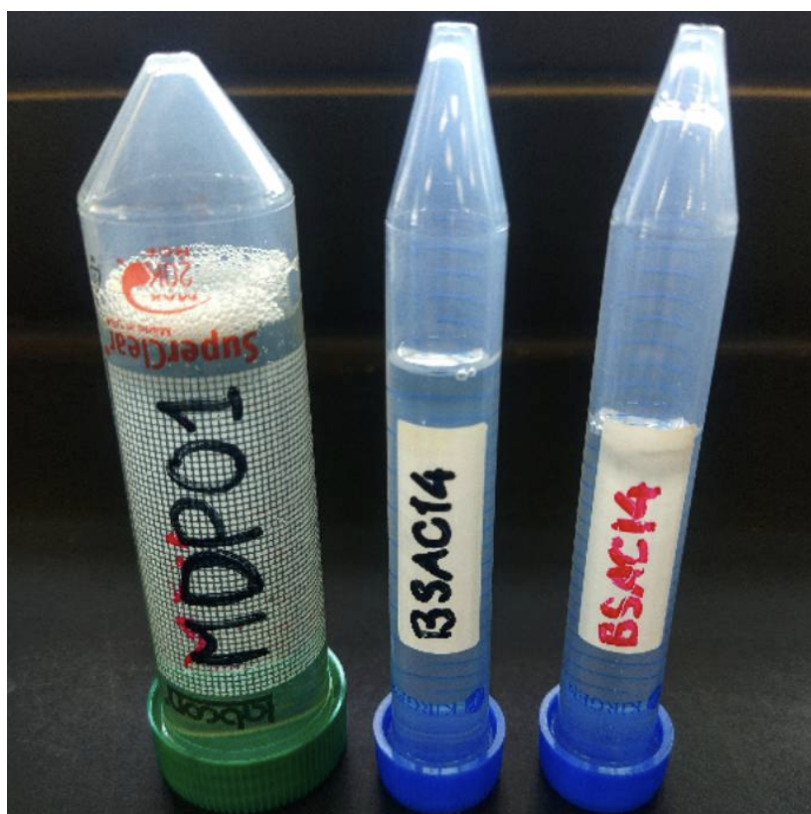


Figure 15: The prototype formulae (MDP01 and BSAC14) developed by Alpha Innovist and Dr. Rojrit Rojanathanes.

Next, according to the criteria table (Appendix B), there are also two more recommended chemicals which are distilled vinegar and hydrogen peroxide. These two chemicals also effectively eliminate mold and are commonly used as household mold remedies. These two substances can be used in standard buildings and those around the Mrigadayavan Palace.

Distilled vinegar 5% (composed of acetic acid 5% and the rest are water), is frequently used in residential applications, has antifungal properties, and is inexpensive. It can stop the growth of molds on porous surfaces and kill the roots of molds within the structure. The acidity of distilled vinegar is powerful enough to break down wide varieties of mold cell walls, effectively killing the mold. While some mold can survive in acidic environments, at the same time, many molds are actually killed by acids. Also, the concentration of acetic acid in distilled vinegar is typically insufficient to promote mold growth. In addition, hydrogen peroxide is another substance that effectively removes molds in households. It can be applied to any material without producing toxic fumes or leaving

behind toxic residue. Additionally, it is accessible and reasonably priced. Apart from using chemicals, there are some methods that the Palace can use to prevent molds.

2. Recommendations for preventing moisture that causes the growth of molds and fungi

Controlling moisture inside the wood to achieve Equilibrium Moisture Content (EMC) can be challenging due to the constantly changing environment that wood may be exposed to. However, several methods can be used to minimize moisture-related issues in wood, such as using different types of wood finishes. For instance, paints are commonly used in canopy areas to protect the wood from water and UV radiation from the sun. Recommended paints for this purpose include Beger and Cutek paints. A comparison of the properties of each paint is presented in Appendix B. Furthermore, physical methods can be employed to control the EMC of wood outdoors. These include elevating the wood structures using a foundation or supports to prevent moisture from seeping into the wood from the ground, providing adequate ventilation, promoting air circulation, and keeping wood structures clean and debris-free to prevent moisture buildups and inhibit fungal growth.

3. Recommendations for wood preparation

For the wood that will be added to buildings, we recommended to prepare the wood as in Appendix G, where there are two main methods: wood impregnation and wood drying. These two methods are recommended to protect the wood from destructive agents such as insects and molds. For wood impregnation, substances that may prevent the growth of molds will be soaked into the wood and work as a protective layer. For wood drying, the moisture content, which is the key component promoting mold growth, will be removed during the drying phase of the process.

4. Recommendations for methods to prevent moisture on porous surfaces and modular design using epoxy

From the findings about using epoxy, we recommend that the palace continue looking into this method as epoxy can be used to cover up the gaps in the structures and is

recommended to prevent the water from going inside ([Xiaomeng, Z. et al. \(2022\)](#); Appendix F). Epoxy resin is a type of plastic and is considered lightweight so that it can be applied in wood canopies. Moreover, epoxy can last up to 20 years as long as proper maintenance is performed. It has high-performance strength and durability. The processing methods can be separated into two types: small cavities and large cavities. For small cavities only require filling up with epoxy and scrubbing with sandpaper to create a smooth surface. It involves wood carving skills for large cavities to shape the newly formed part to match the shape of the repairing wood. As mentioned in the finding, selecting the solvent used with the epoxy resin is challenging as different types of wood, and their environments can influence the effectiveness of the chemicals used for the solvent. Thus, to select a suitable solvent, we recommend that the palace staff consult with more expert scientists, as these methods will be possible after future research on solvents is complete.

5. Recommendation for experimenting to test the effectiveness of the recommended products

We have recommended using chemicals (e.g., BSAC14 and MDP01) that contain borax and BKC, which are chemicals found to kill molds and fungi. Hence, we recommend that the palace experiment with these chemicals to test their effectiveness. The experimental procedures and monitoring form have been constructed (Appendix H), including the basic steps for the Mrigadayavan Palace staff to follow and experiment in the most straightforward approach while continuously monitoring the results. Due to the project's time limit (seven weeks), the team will not be able to collect the results to conclude the effectiveness of each chemical used in the experiment, as it takes a while for the mold to sprout.

Conclusion

The team has investigated the causes of the wood deterioration process on behalf of our sponsor, the Mrigadayavan Palace Foundation, to help them find appropriate preventive actions to preserve and protect the structures of the Mrigadayavan Palace for future generations. Through interviews with numerous professors and the owners of other wooden buildings, literature reviews, and on-site observations and analysis, we have concluded that the problems of wood deterioration throughout the palace were due to moisture, sunlight, mold, and fungi. In addition, inadequate maintenance and care due to the lack of staff also

influenced wood deterioration. Thus, to fulfill our goal of understand the causes of the deterioration process of wood so that appropriate preventive actions can be selected to prevent further damage to the wooden buildings at the Mrigadayavan Palace, our team has provided some guideline recommendations in the form of a booklet along with a digital poster that visitors can scan the QR code to learn more about the causes of wood deterioration and how to prevent it. In this way, the Mrigadayavan Palace Foundation and staff can gain more knowledge and understanding to continue restoring the palace and maintaining the structures for future generations.

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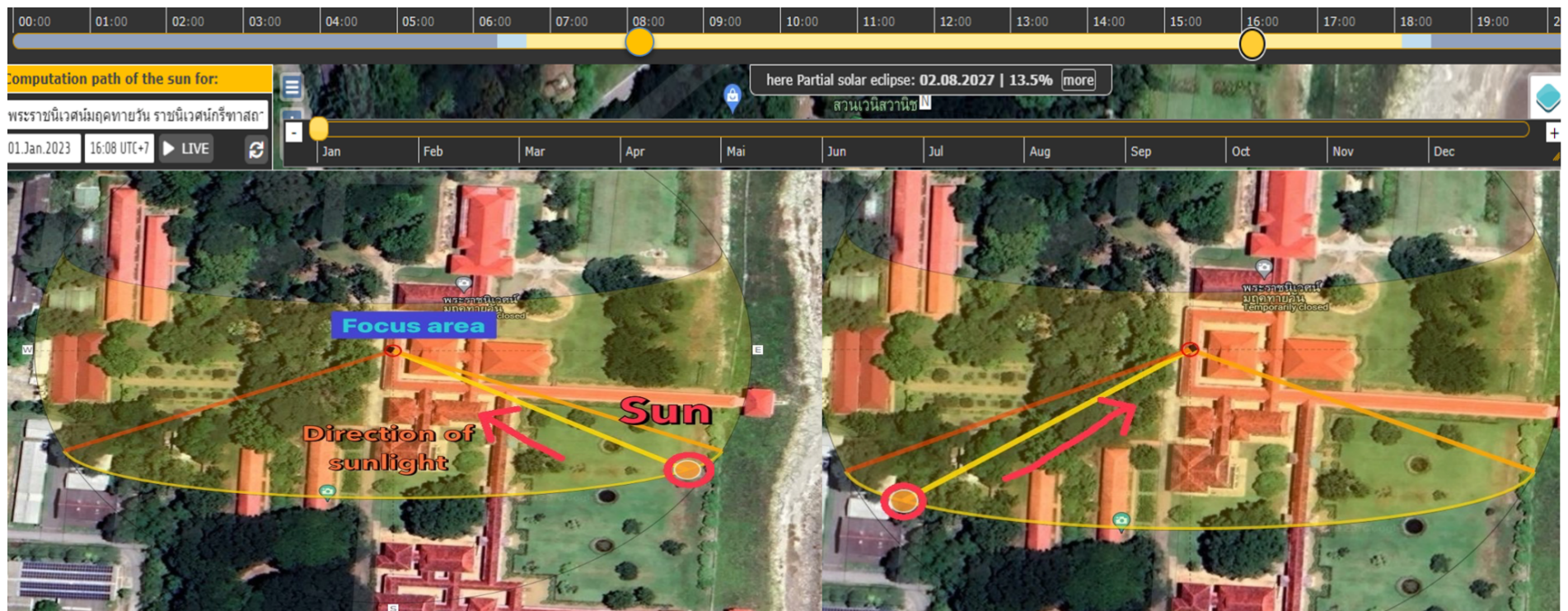
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Appendices

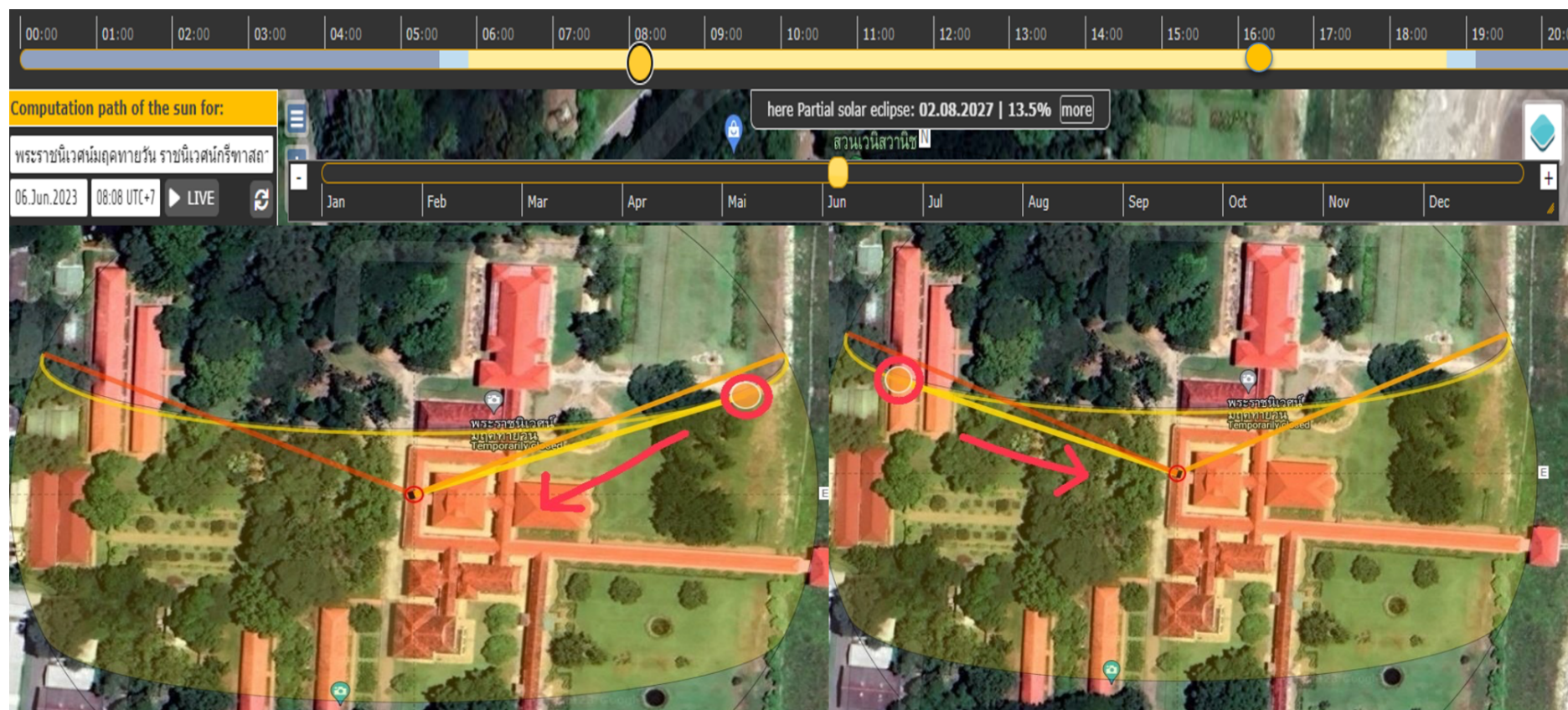
Appendix A - Sun path (from SunCalc)

The sun path shows the direction of the sunlight relative to the focus area. The figures below show the path of sunlight in the morning and afternoon during three time periods of a year (beginning of the year, mid-year, and the end of the year) at the focussed areas (J and B).

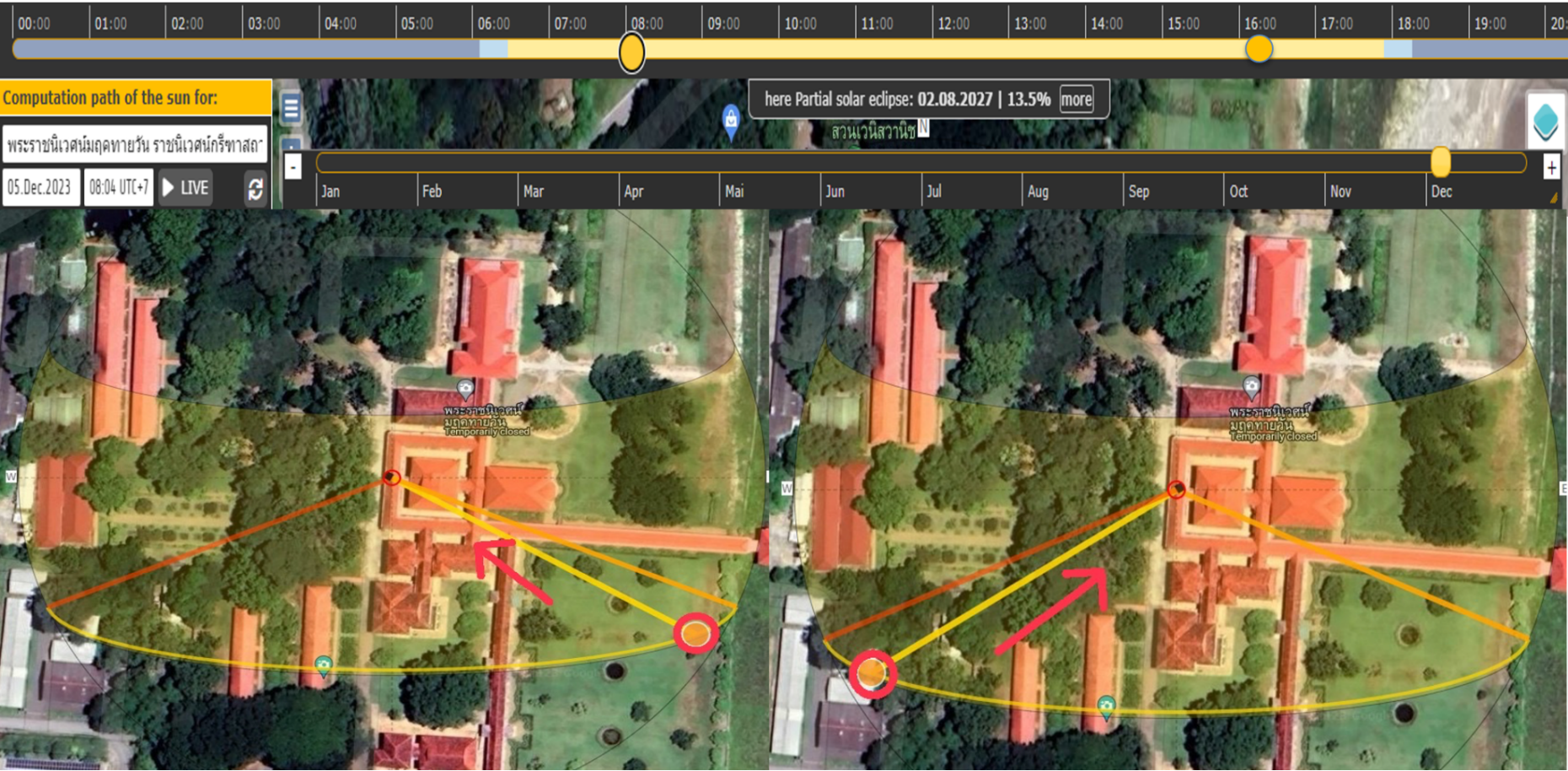
Area B : Beginning of the year



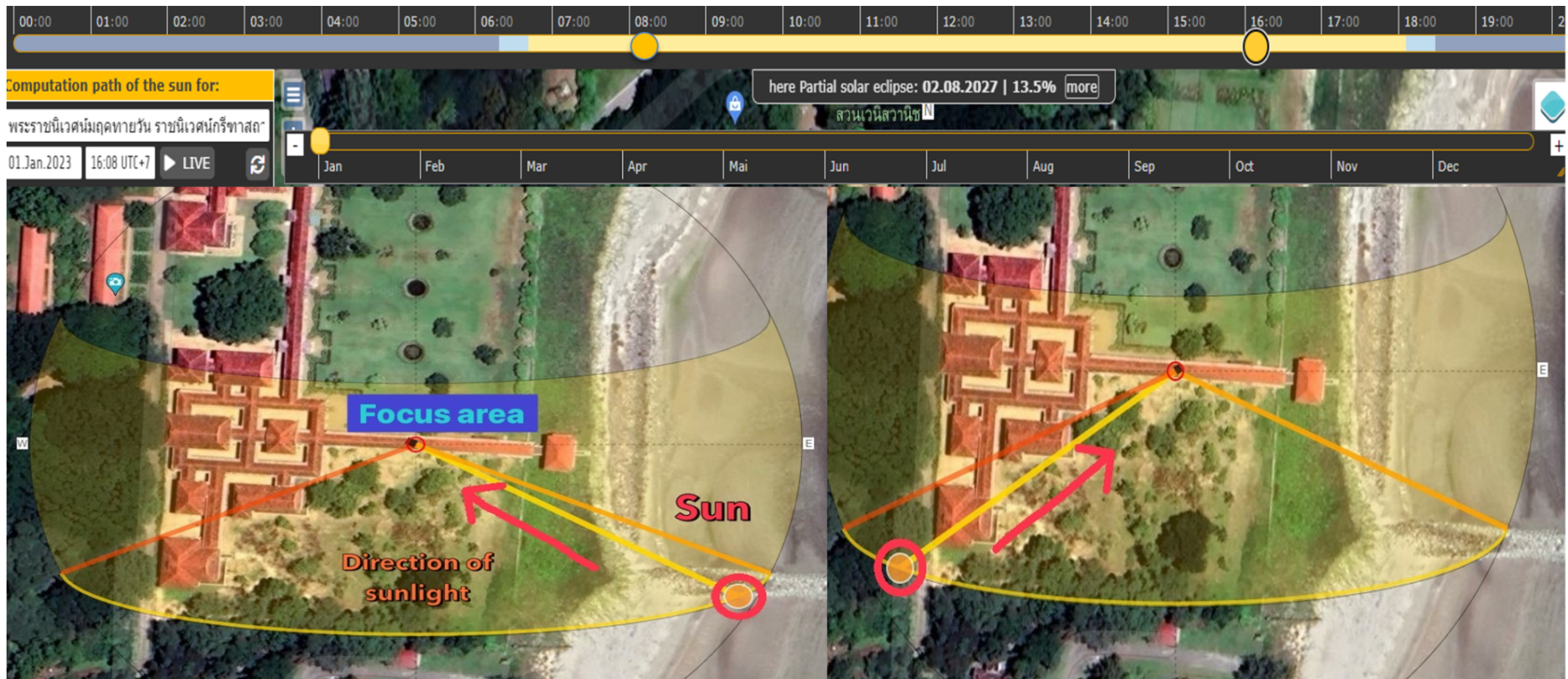
Mid-year



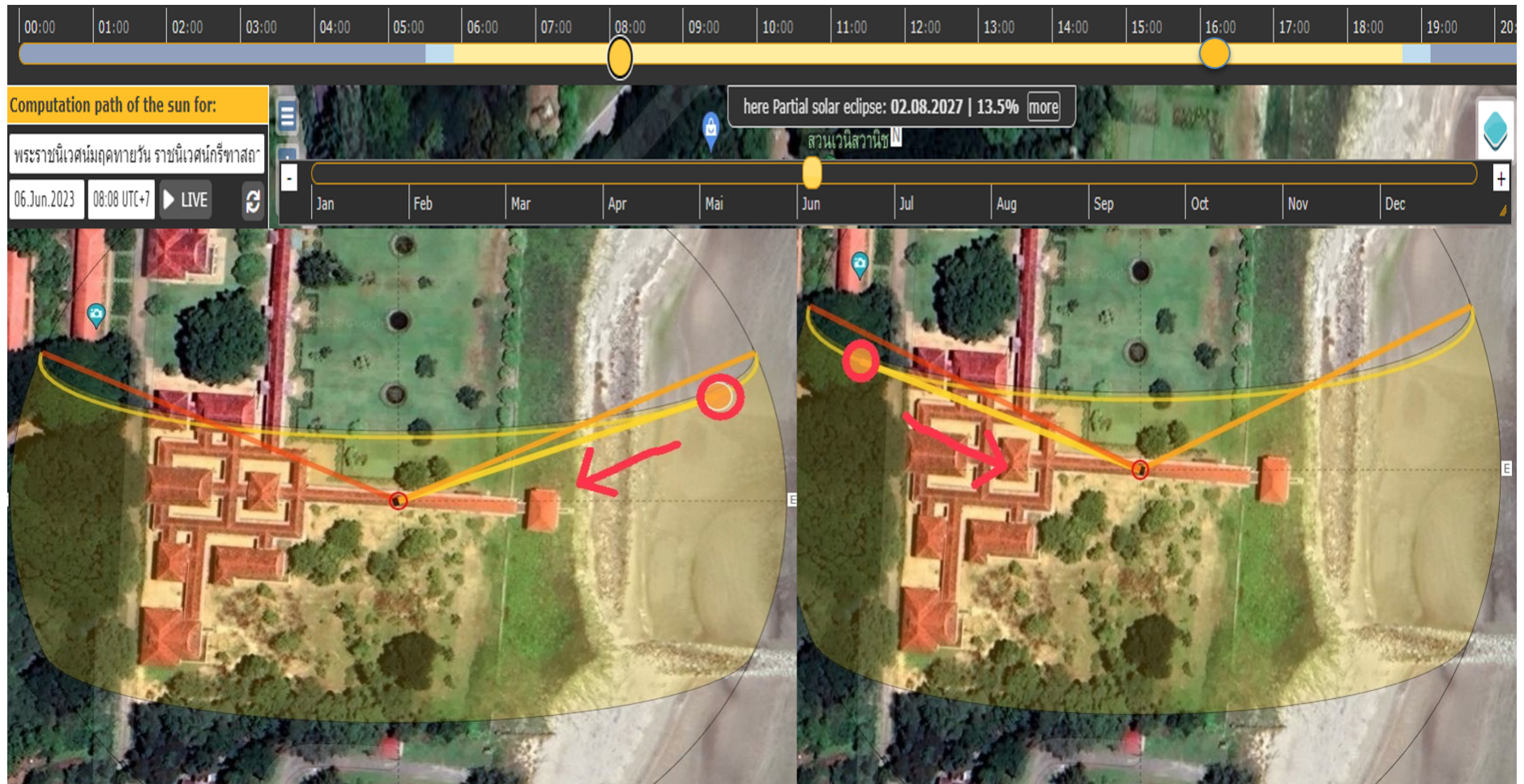
End of the year



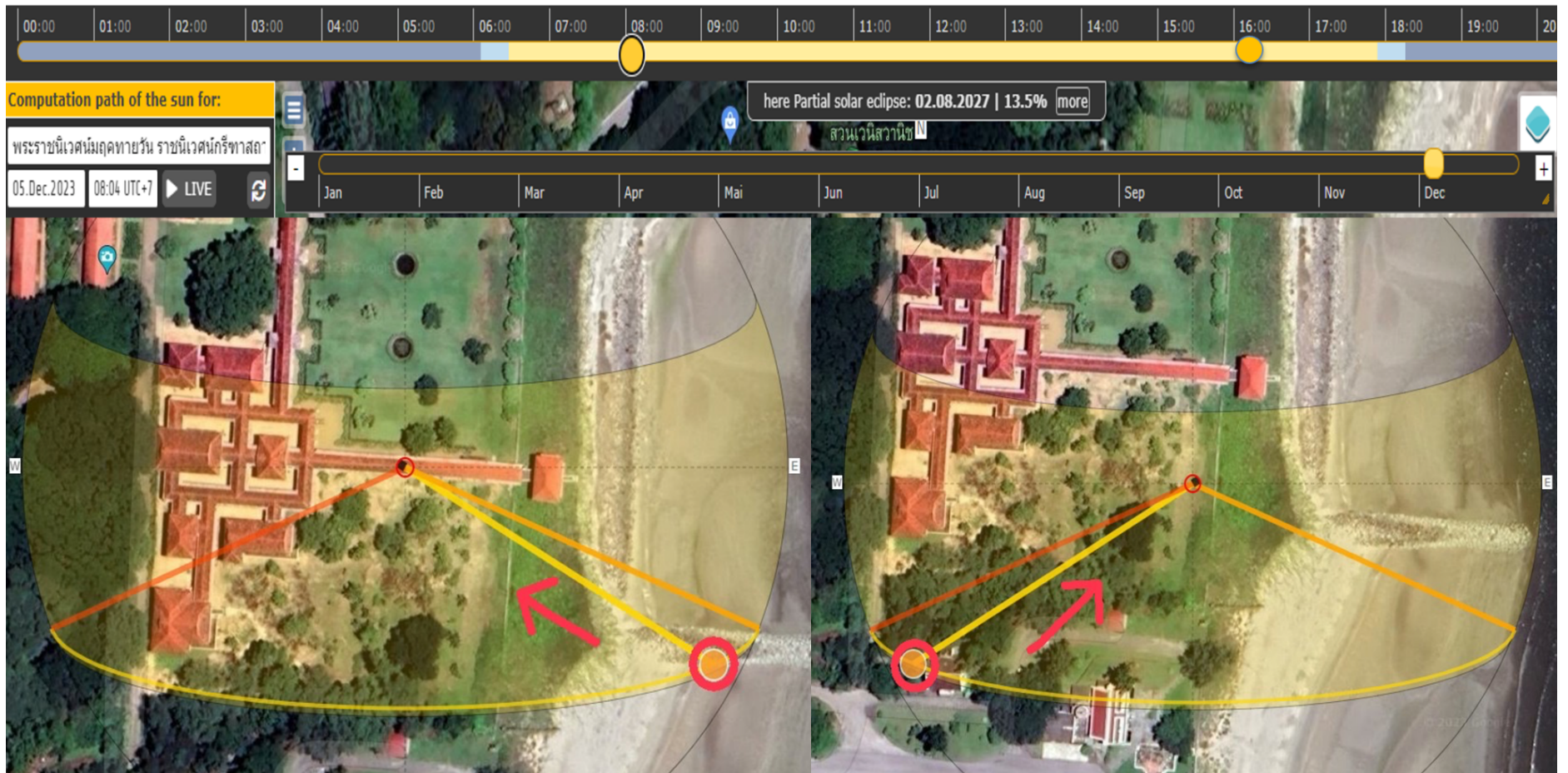
Area J : Beginning of the year



Mid-year



End of the year



Appendix B - Comparative table of chemicals, paints, and wood coatings

****remark**** LC50 is The point estimate of the toxicant concentration that would be lethal and kill 50% of tested animals.

Method	Description	Pros	Cons	Cost	Toxicity	Source(s)	Remark
Methods to clean off and minimize fungi							
Quaternary ammonium compounds (benzalkonium chloride (BKC))	Benzalkonium chloride is a type of Quaternary ammonium compound (QAC) in which it is a disinfectant found in many detergents and odorless antiseptic compounds. In low concentrations, it is used to kill bacteria and fungi	-Non-corrosive and stable at in-use dilution.	- It tends to cling to the surface, making it hard to rinse off which causes taint problems	258 baht per 1kg of Benzalkonium chloride 80%	- Can irritate skin and cause rashes - Do not ingest or breathe - Avoid eye contact LC50 /4 hour - 1.5 mg/L	Mount Sinai Selikoff Centers for Occupational Health (2015) (Cameo (n.d.))	This chemical was suggested by our team since it has been utilized in numerous mold remedy product formulae and can be used to kill molds at low concentrations.

Method	Description	Pros	Cons	Cost	Toxicity	Source(s)	Remark
Borax	Borax is one of the mold killers that can also prevent further mold growth. It can kill mold because of its high pH (most molds prefer to live in lower pH of around 3-7). By using borax, it will create an uninhabitable environment for mold and also destroy the mold spores.	- Cheap, readily available, and affordable - Can remove mold from both porous and non porous surfaces	- It is not completely safe; caution required when in use - Avoid contact with eyes or skin, and never consume it	84 baht for 1 kg	-Noncarcinogenic but causes skin, eye, and respiratory irritation; digestive problems; infertility; kidney failure; shock; death LC50 /4hour - 2.12 mg/L	Jennifer (2019)	This chemical was suggested by our team since it can create an environment that is not suitable for molds and it can kill mold spores.

Method	Description	Pros	Cons	Cost	Toxicity	Source(s)	Remark
Hydrogen Peroxide 3%	Hydrogen peroxide is another good alternative chemical that can kill mold. It is safe, does not damage the environment, and also does not leave behind toxic residues.	- Inexpensive; easy to access - Does not leave behind toxic residue - Safe to use on all materials	- Can cause irritation to skin - Has the potential to inhibit fungal growth on solid surfaces but is not likely effective at killing mold on porous surfaces.	75 baht for 1 L of 3% Hydrogen Peroxide	- Can cause irritation to skin. - Hydrogen peroxide is irritation at contact. - Acute inhalation can cause irritation to the nose, throat, and respiratory tract. LC50 - N/A	The Mould Doctor (n.d.) Yetman, D. (2021)	For hydrogen peroxide 3%, we suggested that it can work inside the household as it does not leave behind toxic residues.

Method	Description	Pros	Cons	Cost	Toxicity	Source(s)	Remark
Distilled Vinegar	Distilled Vinegar has antifungal properties that can remove molds. Vinegar that can be found in households contains 5-8% of acetic acid, which is a strong acid that can disrupt mold growth.	- Work on porous and non-porous surfaces - Non-toxic - Kills up to 82% of mold species - Able to reduce the absorption of water of wood	- Cannot kill every type of mold - have strong smell	HEINZ Distilled White Vinegar 473 ml for (116 baht)	Nontoxic and eco-friendly LC50 - 5620ppm	Yetman, D. (2021)	Our team suggested distilled vinegar for household use as it is effective in killing molds and also inexpensive.

Method	Description	Pros	Cons	Cost	Toxicity	Source(s)	Remark
Filmprotector	Filmprotector is made from natural rubber and used for temporary coatings on a surface of material that needs to be protected from molds.	- Quite strong - Able to protect the surface of a material from scratches, bumps, and sparks - Suitable for removing mold from concrete surfaces	- May work only at the surface level (have never tried on wood)	450 baht for 1 L of Filmprotector or	Friendly to living beings and the environment	Hinchiranan, N. (2023)	Since this product had never been tried on wood before, but has been proven to remove mold from concrete surfaces.

Method	Description	Pros	Cons	Cost	Toxicity	Source(s)	Remark
Chlorothalonil 75%	Chlorothalonil is a fungicide used to control fungi that grow on trees, vegetables, small fruits, and other crops. It also controls mold, mildew, algae, bacteria, and fruit rot. In addition, it can be used to control certain pests like mites and ticks, and can be used to protect wood. One of the top used fungicide active ingredients in the USA.	- It interferes with the enzyme systems of the fungus, which make the fungi unable to perform essential functions related to growth	- Quite toxic and not environmental friendly	470 baht for 1 kg of Chlorothalonil 75%	- Contact can irritate the skin and eyes - Breathing can irritate nose, throat, and lungs - May be carcinogen in humans as it is shown to cause kidney cancer in animals LC50/1 hour- 92 mg/m³	Perma-Chin k (2021)	This product is also effective in killing molds. However, it is quite toxic, so we do not recommend it for the palace.

Method	Description	Pros	Cons	Cost	Toxicity	Source(s)	Remark
Chlorine Dioxide	Chlorine dioxide is a chemical that is known for its mold killing properties. At room temperature, it dissolves into a gas state in the atmosphere, breaking down to oxygen when it is exposed to the atmosphere. Chlorine dioxide is also part of the substances in the product called vital oxide that is used for hospital disinfectant cleaners and mold killers.	- It is capable of eliminating bacterial spores, legionella, salmonella, and other harmful microorganisms, including mold spores.	- It is highly flammable and a reactive gas - Explosion hazards	291.39 baht 1 L of Chlorine Dioxide	- Unsafe if consumed - In concentrations over 10%, it is a combustible gas which explodes violently in the air - Almost any source of energy(e.g., heat, sunshine, sparks) can ignite it LC50 - 0.29 mg/L	Elgazar, R. and Kemper, J. (n.d.)	It is not advised for the palace to use this product because it is a reactive gas and very combustible.

Method	Description	Pros	Cons	Cost	Toxicity	Source(s)	Remark
Iodophor (iodine)	Iodophor is composed of iodine that is combined with a substance that can help it dissolve, making it used as a disinfectant. Iodophor also penetrates the cell walls and membranes of mold cells which make it effective in eliminating molds.	- Less expensive - Non-toxic and effective at killing molds	- Leave behind a yellowish residue - One time use	190 baht for 450ml of Iodophor (iodine)	Non-toxic and non-irritating LC50 - 25.5 mg/m³	More Beer! (n.d.)	This substance can help eliminates molds, but it leaves a yellow residue that tarnishes the natural color of the building.

Method	Description	Pros	Cons	Cost	Toxicity	Source(s)	Remark
DDAC 50%	DDAC is an antiseptic that is effective against molds. Lipid bilayers of molds are dissociated and intermolecular connections are disrupted. It has a wide range of bactericidal and fungicidal effects.	It is a strong chemical that is effective in killing molds.	- Quite toxic and corrosive to skins	456.45 baht for 1L of Didecyl Dimethyl Ammonium Chloride (DDAC) 50%	- Harmful if swallowed. - Causes severe skin burns and eye damage. - Very toxic to aquatic life. - Do not inhale dust/fumes/gas /mist/vapors/spray LC50 - 70 mg/m³	Yetman, D. (2021)	This chemical is also effective in killing molds. However, it is quite toxic so we do not recommend using this for the palace.

Method	Description	Pros	Cons	Cost	Toxicity	Source(s)	Remark
Green Methods							
Tea tree oil	Tea tree oil is an essential oil commonly used for repelling insects and as an antiseptic.	- The main active compounds (alpha terpineol and terpene-4-ol) can destroy cell walls of the molds	- May not be very strong	114 baht for 25g of tea tree oil	N/A	Colorado Property Group (n.d.).	-none-
Citrus Extract	It works as an all-natural fungicide.	- Have potential antifungal effects as it disrupts the fungal cell membrane	- May not be very strong	2889 baht for 1 kg of orange citrus extract (powder)	N/A	Colorado Property Group (n.d.).	-none-

Method	Description	Pros	Cons	Cost	Toxicity	Source(s)	Remark
Lemon	The use of lemons is another natural method of removing molds, as they contain a high concentration of acid which helps break down mold structures.	- High concentration of acid which helps break down molds	- May not be very strong	600 baht for 1 kg of lemon	N/A	Colorado Property Group (n.d.).	-none-

Method	Description	Pros	Cons	Cost	Toxicity	Source(s)	Remark
Methods for fungi prevention (paint)							
Cutek	Cutek paint has the approval certificate from Thailand Institute of Scientific and Technological Research (TISTR). It provides protection against moisture, eliminates the need to hire a professional painter, allows for faster and easier application, and does not require scrubbing of the wood surface prior to application of paint.	- Easy to apply - Certified that it can prevent fungal grow from Thailand Institute of Scientific and Technological Research (TISTR)	- Before applying the paint, there is a need to apply antifungal chemicals and clean off with water. Hence, it is difficult to dry off the wood after soaking it in water	For Cutek Extreme, 2615 baht per 2.50 L; for Cutek Colourtone, 185 baht per 0.08 L	May cause skin irritation	Cutek Official Website (n.d.)	-none-

Method	Description	Pros	Cons	Cost	Toxicity	Source(s)	Remark
Methods for fungi prevention (wood finish)							
Teak oil	Deck stain is a type of paint consisting of pigments, solvents, and binders that are commonly used to color wood and inhibit discoloration. Used for wooden floors.	- UV protection - Resists cracking and peeling	- Requires consistent maintenance	Beger: 1004 baht per 3.785 L	May cause skin irritation	Barron, J. (2020)	-none-

Method	Description	Pros	Cons	Cost	Toxicity	Source(s)	Remark
Deck stain	Deck stain is a type of paint consisting of pigments, solvents, and binders that are commonly used to color wood and inhibit discoloration. Use for wooden floors.	- Provides protection from ultraviolet sun damage and moisture damage, helping maintain and improve wood appearance	- Does not last long; requires re-staining often - Certain woods do not hold stain well - Requires experienced applier	Beger: 1175 baht per gallon	Can cause mild irritation when in contact with skin or eyes	Dunbar Painting (2019)	-none-

Method	Description	Pros	Cons	Cost	Toxicity	Source(s)	Remark
Polyurethane	Polyurethane is a varnish and synthetic microscopic chain of resin molecules tightly bound together to form a protective layer as it dries and gives wood a glossy finish. It is used for finishing wooden floors or wooden items.	- High water resistance - High abrasion resistance - Lasts long (3-6 years)	- Has been used at the palace before and found ineffective as it prevents moisture from getting out of wood	TOA: 1445 baht per gallon	May cause dizziness when inhaled	Precision Urethane & Machine (n.d.)	-none-

Compare Type of Paint

Types of paint	Description	Pros	Cons	Source(s)
Oil-based paint	Oil-based paints consist of ground-colored pigments mixed with oils with various levels of solvent depending on the paint type and quality. They contain solvents with a high Volatile Organic Compound (VCO) ratio.	- Highly durable - Creates glossy finish - Waterproof when dry - Suitable for both indoor and outdoor use	- Toxic (mask and ventilation system required) - Long drying time (6-8 hours) - Solvent required to clean - Viscous if applied too quickly	Faessler, M., Faessler, T. (2021)
Acrylic paint	Acrylic paints consist of a water-soluble formula containing pigments in a polymer emulsion. This type of paint can be used with a wide range of wood and has thus become increasingly attractive over the years.	- Quick drying time (~30 minutes) - Non-toxic; safe for indoor use - Little odor - Low VCO	- Easily chipped - Lower gloss compared to oil paint	Faessler, M., Faessler, T. (2021)

From the following table, we have concluded that the most recommended chemicals for mold minimization methods are quaternary ammonium compounds (benzalkonium chloride) and borax. There is a product developed by a start-up company called Alpha Innovist, along with Assistant Professor Dr. Rojrit Rojanathanes, which has benzalkonium chloride and borax as components. Our team tested it in our experiment to see if it can be prolonged in wood and also the length of time it can prevent molds from re-entering the wood. The reason why we chose these chemicals are based on the advantages, disadvantages, cost-effectiveness, and toxicity of each chemical. Furthermore, there are two substances that our team also recommends for household mold remedies, which are hydrogen peroxide 3% and distilled vinegar. These two substances are also excellent for household use as they are not that strong and also inexpensive.

Appendix C - Interview questions for Mrigadayavan Palace workers

- Where are the molds mainly located?
- Which areas contain more/less molds?
- Which types of molds grow in which areas?
- What types of wood are used for the buildings?
- What methods have you used previously to eliminate molds? Were they effective?
- How did you clean the areas that were affected by molds previously?
- Which area/s of Mrigadayavan Palace has the highest mold damages?
- How is the atmosphere in the Mrigadayavan Palace?
- Which types of wood have been affected by molds the most?
- How do the cleaners clean the buildings?
- Which parts of the buildings were affected by molds?
- How important is the Mrigadayavan Palace?
- How does the modular design affect the growth of molds?
- What paint brand/s have you used?
- What experiments have been done for removing molds?

Appendix D - Interview questions for experts

1) Expert Profile



Assist. Prof. Dr. Jittra Piapukiew

Professors at Department of Botany, Chulalongkorn University

Research interests:

- Diversity of different groups of fungal mycorrhiza
- Application of mycorrhiza for agriculture
- Study of the structure of ectomycorrhiza population
- Study the genetics of ectomycorrhiza population
- Diversity of endophytic fungi

Our team wanted to interview her as she is a mold and fungi expert.

Interview questions:

- How do mold and fungi populate?
- Factors affecting mold and fungi growth
- What moisture level on wood causes mold to grow?
- How long does it take for mold to grow?
- How to identify mold and fungi

- How to distinguish mold from dust and dirty black spot
- Suggestions for mold prevention and minimization method
- Suggestions for alternative greener methods

Summary:

Ajarn Jittra told us about molds and methods used to eliminate them. To summarize, there are many types of molds that cause a variety of effects on buildings and human health. She also mentioned other factors that influence mold growth, such as low pH, and high sunlight and UV content.

In addition, she explained in detail that there are many types of mold and that they grow in humid environments, causing health concerns if left untreated. From viewing our photos of the palace structures, Ajarn confirmed that they were black molds since they were black in color.

Ajarn then explained about methods that are suitable for eliminating molds, including using chemicals (distilled vinegar, borax, and hydrogen peroxide) and cleaning the area thoroughly.

2) Expert Profile



Associate Professor Dr. Panan Rerngsamran

Professors at Department of Microbiology, Chulalongkorn University

Our team wanted to interview her as she is a mold and fungi expert.

Interview questions

- Confirm knowledge on what types of molds grow on wood
- How to get moisture out of the wood
- How to identify mold and fungi
- How to distinguish mold from dust and black spot
- Suggestions for mold prevention and minimization methods
- Ask about chemicals (such as the effectiveness of sodium hypochlorite)
- Suggestions for alternative greener method
- Ask about what should be included in the simple experiment we plan on doing
Mrigadayavan Palace
- How to spot molds with bare eyes

Summary:

Ajarn Panan confirmed our knowledge about molds/rot when we interviewed her. She spoke about the types of mold (soft rot, brown rot, and white rot), and also told us about ways to identify molds (visual identification and comparing them to lab samples). Also, she spoke about one of her studies which uses bacteria to kill molds.

3) Expert Profile



Prof. Dr. Napida Hinchiranan

Professors at Department of Chemistry Technology, Chulalongkorn University

Research interest:

- Chemical Modification
- Pyrolysis of Waste Tyres and Plastics

Our team interviewed her as we learned about her product, *Filmprotector*, a film that has the potential to remove molds from walls.

Interview questions

- Ask about what *Filmprotector* can do
- Ask about her opinion on using *Filmprotector* on the wood at the palace

Summary:

We interviewed Ajarn Napida about her product (Filmprotector). She gave us a detailed summary about how to use the product. Filmprotector is a film made from natural rubber that peels off substances on its surface (e.g., molds and bacteria) while maintaining paint coatings. The product was used in our experiment (Appendix H).

Appendix E - Interview questions for wood experts

1) Ruen Urai

- What kind of wood is used for these buildings?
- Have you ever experienced decay/rotting?
 - How did you solve these problems?
 - What did you use?
- Do you use anything to preserve the wood? (chemicals, etc.)
- How do you clean the wood surfaces? How often?

2) Jim Thompson

- What kind of wood is used for these buildings?
- Have you ever experienced decay/rotting?
 - How did you solve these problems?
 - What did you use?
- Do you use anything to preserve the wood? (chemicals, etc.)
- What are some of the methods used to clean the wood?
- How do you prevent the wood from moisture?

3) Sanctuary of Truth

- What kind of wood is used for these buildings?
- Have you ever experienced decay/rotting?
 - How did you solve these problems?

- What did you use?
- Do you use anything to preserve the wood? (chemicals, etc.)
- How do you clean the wood surfaces? How often?

Appendix F - Methods for filling in gaps in wood structures

Method 1: Filling smaller cavities with epoxy

The simplest method to address small cavities is to fill them with an epoxy/filler mix. However, this approach is only suitable for areas of approximately 12mm depth or the size of a golf ball, as larger volumes may produce an exothermic reaction that causes the epoxy to heat up and weaken. The following steps should be followed to ensure the best results:

- **Prepare the surface:** Once the small cavity is excavated, prepare the surface as usual and ensure that the area is completely dry to prevent any further moisture damage.
- **Wet out:** Once you are certain that the area is dry, wet it out with a mix of Epoxy resin and Fast hardener.
- **Thicken epoxy with high-density filler:** Then, thicken the epoxy with a high density filler, such as Colloidal Silica, High Density Filler, or Microfibres, to achieve a peanut butter consistency that is ideal for gap filling, fairing putty, and bonding uneven surfaces.
- **Apply epoxy/filler mix:** Use a squeegee or mixing stick to trowel in the mix and ensure that the cavity is filled with this thickened epoxy. Smooth it flush with the wood's surface and quickly remove any excess before the epoxy begins to cure.
- **Cure:** Finally, allow the mix to cure thoroughly and sand down the filled cavity only after it has fully cured.

Method 2: Filling large cavities with wood

Larger cavities require a more involved and labor-intensive response. This method involves carving a plug, to the same shape as the cavity and bonding it in place using epoxy to create a repair that will restore the area's original strength.

The following steps should be followed to ensure the best results:

- **Prepare the plug:** Firstly, prepare the plug, and if the same kind of wood is available, it is recommended to use it.

- Carve the cavity, applying bevel to the sides: Carve the cavity into a shape that will make fitting the plug easier and bevel the sides of the cavity. The longer the bevel on the sides running across the grain, the stronger the repair will be. An 8-to-1 bevel (8cm long for every 1 cm deep) or greater will get you closest to the original strength of the wood. Then check the plug for fit. A perfect fit is not entirely essential, as your thickened epoxy will fill fairly large gaps. Now, prepare the surfaces for bonding.
- Wet out: Wet out the bonding surfaces of both the cavity and the plug with a mix of Epoxy Resin and Fast Hardener.
- Thicken epoxy using high density filler: Thicken the epoxy using a high density filler, such as Colloidal Silica, High Density Filler, or Microfibres, to achieve a moderately thickened, mayonnaise consistency that is suitable for general bonding, hardware bonding.
- Apply epoxy/filler mix: Using a mixing stick, apply the epoxy to the cavity's surfaces and ensure that enough of the thickened compound is applied to fill any gaps.
- Fix and clamp plug: Insert the plug into the cavity, and any excess epoxy should squeeze out of the joint. Clamp the plug into position and remove any excess epoxy before it starts to cure. If you need to hold the plug in place, use weights or staples.
- Cure: Finally, allow the mix to cure thoroughly before removing any clamps. Sand down the filled cavity once it has fully cured.

Appendix G - Wood preparation

Wood preparation is needed to prepare wood before use to maintain its conditions as long as possible. One method that is suitable for wood preparation is wood preservation, which is to apply wood preservatives on the wood and let it absorb through the wood cells, leading to increased wood durability against wood destroying agents, either living or non-living materials. The increase of the wood durability will result in expanding the wood lifespan, which is useful in areas that are hard to replace. The wood preservation needs to consider two things: wood preservatives and the processes. Firstly, the wood preservatives are separated into three types: water-borne, oil-borne, and light organic solvent preservatives. Each type of preservative is suitable on different types of wood and uses. Second is the processes, of which there are two types: non-pressure and pressure. The non-pressure processes are brush or spray treatment, dipping, steeping, cold soaking, hot and cold baths, and diffusion. The advantages of pressure processes are that they can put the preservatives deeper and more evenly through the wood by using a machine called an impregnating tank. It is the most common process; however, the needed equipment (including things other than impregnating tanks) are expensive. Two types of pressure processes are full-cell and empty-cell processes. The full-cell process will impregnate the preservatives into the wood cells as much as possible until it fills all of the holes. The empty-cell process will only impregnate the preservatives into wood cells in moderate amounts and leave some holes empty, so this process should be used for wood that does not need to be all covered up with preservatives.

According to the Sanctuary of Truth, since they used the wood to construct a big castle which is not convenient to replace and fix often, they did a wood preparation process which resulted in around 30 to 50 years. The Sanctuary of Truth is facing a lot of wood decaying factors (e.g., salt spray due to location on the seaside, extreme heat, rain). Therefore, the application of the pressure wood preservation process is chosen which has to be done to the wood twice (before and after wood processing) to ensure that the preservative chemicals stay in the wood.

Appendix H - Experiment and monitoring form details

For the experiment which our team has conducted at Mrigadayavan Palace, all of the instructions are in the lab manual. These include objective, brief introduction, how to apply each chemical, materials, experiment procedure, and lab safety precautions. In addition, the lab manual is available in both English and Thai format for the reader's convenience. Also, to make the experiment easier to understand and follow, our team developed a flowchart of the experimental steps. Lastly, our team also created a monitoring form for the palace staff members to observe the results over time.

Lab manual

Objectives: To examine how long the chemicals can stay in the wood in order to minimize the growth of existing molds by looking at the time they can prevent molds from re-entering the wood.

Introduction

In this experiment, the solutions are used on bare teak wood to test whether the solutions are effective in minimizing mold growth on teak wood by looking at the length of time they can prevent the molds from re-entering the wood. The teak wood that will be tested will be the Palace wood where the wood is already painted. This experiment is conducted for the purpose of testing the effectiveness of the solutions that were applied in the environment where the area is surrounded by a high moisture content. In addition, the experiment will check whether the solutions are suitable for use in the Mrigadayavan Palace and thus used to create a guideline for the Mrigadayavan Palace Foundation to support the wooden structure maintenance of the palace and to prevent new molds from developing and minimize the growth of existing molds.

How to Apply Each Methods

The chemicals used for this experiment are Filmprotector, BSAC14 formulas which combine Benzalkonium chloride with Borax and a Booster, MDP01 formulas which combine Benzalkonium chloride with enriched Borax. Before applying these chemicals into the wood, read the instruction and chemical safety manuals before starting the experiment.

BSAC 14 Formula

- Pour 15 ml of **BSAC 14 Formula** to mixed with 1.5L of water in a bucket, The solution is **diluted 100 times**. **The water that is used to mixed with the solution need to be deionized water or normal drinking water** (Do not use tap water!!!)
- After we get a solution with 100 times diluted, transfer 150ml of the solution into a new bucket.
- A bucket with 150ml of the solution is then mixed with 1.5L of water to make it **diluted 1000 times**.
- At the end, you will get a solution with **diluted 100 times** and a **diluted 1000 times** in 2 buckets.

MDP01 Formula

- Pour 15 ml of **MDP01 Formula** to mixed with 1.5L of water in a bucket, The solution is **diluted 100 times**. **The water that is used to mixed with the solution need to be deionized water or normal drinking water** (Do not use tap water!!!)
- After we get a solution with 100 times diluted, transfer 150ml of the solution into a new bucket.
- A bucket with 150ml of the solution is then mixed with 1.5L of water to make it **diluted 1000 times**.

- At the end, you will get a solution with **diluted 100 times** and a **diluted 1000 times** in 2 buckets.

Filmprotector

- Pour the required amount of **latex mixture** from the packet into the bucket.
- Dip the roller into the bucket and apply in an upward motion to the area you want to remove molds from.
- Wait for the **latex mixture** to dry, then apply two more coats, each round waiting for the latex to dry completely before applying a new layer.
- After three rounds, wait for the latex to completely dry and then peeled off the film.

Chemical Safety

Borax

- Wear gloves and a mask.
- Use borax in a well-ventilated area.
- Remove contaminated clothing. Change clothes if borax touches it. Wash hands thoroughly before eating, drinking, putting on makeup, applying cosmetics, or using the toilet after using borax.
- If borax powder gets in your eyes or on your skin, flush with water for at least 15 minutes.
- Begin rescue breathing in case of accidental inhalation.
- In case of exposure, get medical help if needed.
- Call Poison Control and other emergency services if needed.

Benzalkonium chloride

- In case of accidental inhalation, inhale fresh air and seek medical attention immediately.
- If contact with skin, remove all contaminated clothing immediately. Rinse skin with water/shower. Seek medical attention immediately.
- In case of eye contact, rinse out with plenty of water. Immediately call the ophthalmologist. Remove contact lenses.
- If swallowed, have the victim drink water (two glasses at most); avoid vomiting (risk of perforation). Seek medical attention immediately. Do not attempt to neutralize.

Filmprotector

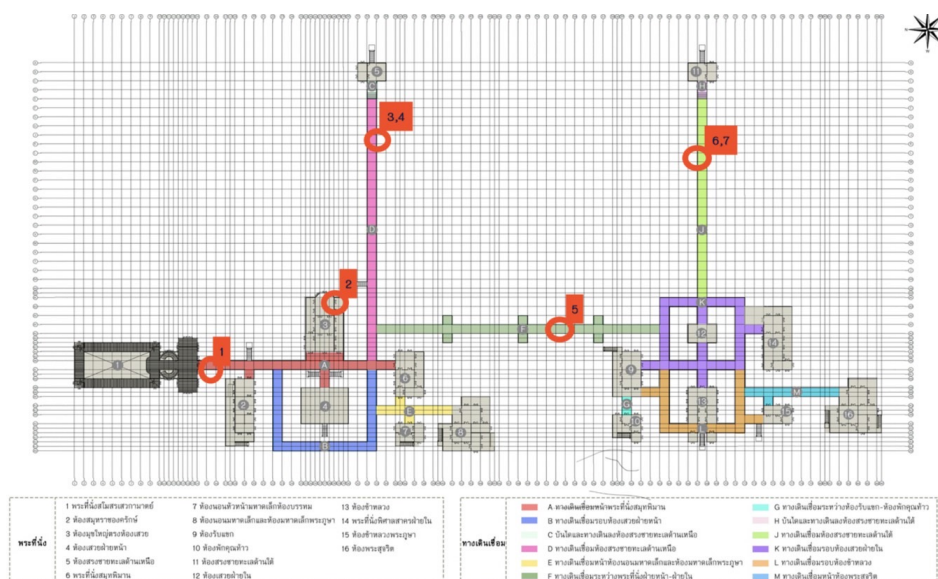
- During rest, immerse the roller in a bucket of latex to prevent the film from hardening.
- Gloves should not be used while applying as this may result in the glove sticking to the roller.
- Latex is safe if it sticks to your hands and can be peeled off, but should not be put into your mouth.

Materials

1. Two pieces of smooth surface wooden plank (Mold grow on the surface)
2. 4 Brushes
3. Paint roller
4. Bsac 14 Formula
5. MDP01 Formula
6. Filmprotector
7. 5 clean rags
8. Mixing Bucket x 5
9. Measuring Cylinder 20ml x2
10. Measuring Cylinder 200ml x2
11. Water bottle 1.5 L x 5 bottles

Experimental Procedure

For BSAC 14 formulas and MDP01 formulas



1. First, use a clean wet rag to clean off the surface before applying the solution. There are seven areas where the solutions will be tested.
1. Next, bring out BSAC 14 formulas and MDP01 formulas (Read how to apply the solution first before proceeding to the next steps)
2. Use a brush to apply each solution into the wooden structure. Wait 15-30 minutes to let it dry.
3. Re-apply the solution again
4. Observe the woods once a week to check whether the mold has grown back and record the date in the monitoring form.

For Filmprotector:

1. Take two pieces of smooth wood that have mold on the surface.
2. Pour the latex out of the packaging. Into the bucket in the amount you want to use.
3. Dip the roller into the bucket. and apply it in an upward direction only on to 2 smooth wooden boards
4. Wait for the latex to dry. Apply again 2 more times. Each round must wait for the latex to dry completely before applying a new layer.
5. After three rounds, wait for the latex to dry completely and peel off the film.
6. Observe the woods once a week to check whether the mold has grown back and record the date in the monitoring form.

Laboratory Safety Precaution:

1. Goggles or eye protection.
2. N-95 respirator or one that provides even more protection. (check packaging for “N-95”)
3. Long-sleeved shirt.
4. Protective gloves.
5. Long pants.
6. Waterproof boots.
7. After the experiment is complete, wash hands with soap.

คู่มือปฏิบัติการ

วัตถุประสงค์: เพื่อตรวจสอบระยะเวลาที่สารเคมีสามารถอยู่ในเนื้อไม้เพื่อลดการเจริญเติบโตของเชื้อราที่มีอยู่ โดยดูจากระยะเวลาที่สามารถป้องกันไม่ให้เชื้อรากลับเข้าไปในเนื้อไม้ได้

บทนำ

ในการทดลองนี้ ใช้น้ำยา บนไม้สักเพื่อทดสอบว่าน้ำยามีประสิทธิภาพ ในการลด การเจริญเติบโต ของเชื้อราบนไม้สักหรือไม่โดยดูเวลาที่สามารถป้องกันไม่ให้เชื้อรากลับเข้าไปในเนื้อไม้ ไม้สักที่นำมาทดสอบจะเป็นไม้รังซึ่งไม้ทำสีไว้แล้ว การทดลองนี้ ดำเนินการโดย มีวัตถุประสงค์ เพื่อทดสอบประสิทธิภาพของสารละลายที่ใช้ในสภาพแวดล้อมที่มีความชื้นสูงล้อมรอบบริเวณ นั้น นอกจากนี้ การทดลองจะตรวจสอบ ว่าสารละลายนั้นเหมาะสม ที่จะใช้ ใน พระราชานิเวศน์ - มฤคทายวันหรือไม่ จากนั้นจึงนำมาจัดทำเป็นแนวทางสำหรับมูลนิธิพระราชานิเวศน์มฤคทายวัน เพื่อสนับสนุนการบำรุงรักษาโครงสร้างไม้ของพระราชวัง และเพื่อป้องกันไม่ให้เชื้อ ราเติบโต อีก ทั้งยังลดการเติบโตของเชื้อราที่มีอยู่ในบริเวณพระราชานิเวศน์

วิธีการใช้สารเคมีแต่ละชนิด

สารเคมีที่ใช้ในการทดลองนี้คือ Filmprotextor, สูตร BSAC14 ซึ่งรวม Benzalkonium chloride กับ Borax และ Booster, สูตร MDP01 ซึ่งรวม Benzalkonium chloride กับ Enriched Borax ทั้งนี้ ก่อนใช้สารเคมีเหล่านี้กับไม้ ควรอ่านคำแนะนำและคู่มือการใช้สารเคมี ก่อนเริ่มการทดลอง

BSAC 14 Formula

- เทสูตร BSAC 14 จำนวน 15 มล เพื่อ ผสมกับน้ำ 1.5 ลิตรในถัง ซึ่งทำให้เกิด สารละลายเจือจาง 100 เท่า **น้ำที่ใช้ผสมน้ำยาต้องเป็นน้ำปราศจากไอออนหรือน้ำดื่มธรรมดา** (ห้ามใช้น้ำประปา!!!)
- หลังจากที่เราได้สารละลายที่เจือจาง 100 เท่าแล้ว ให้ถ่ายสารละลายนั้นจำนวน 150 มล. ลงในถังใหม่
- นำถังที่มีสารละลายจำนวน 150 มล มาผสมกับน้ำ 1.5 ลิตร เพื่อทำให้เกิดการ เจือจาง 1,000 เท่า
- ในตอนท้ายคุณจะได้สารละลายที่เจือจาง 100 เท่าและเจือจาง 1,000 เท่า ใน 2 ถัง

MDP01 Formula

- เทสสูตร MDP01 Formula จำนวน 15 มล เพื่อ ผสมกับน้ำ 1.5 ลิตรในถัง ซึ่งทำให้เกิดสารละลายเจือจาง 100 เท่า **น้ำที่ใช้ผสมน้ำยา ต้องเป็นน้ำปราศ จากไอออน หรือน้ำดื่มธรรมดา** (ห้ามใช้น้ำประปา!!!)
- หลังจากที่เราได้สารละลายที่เจือจาง 100 เท่าแล้ว ให้ถ่ายสารละลายนั้นจำนวน 150 มล. ลงในถังใหม่
- นำถังที่มีสารละลายจำนวน 150 มล มาผสมกับน้ำ 1.5 ลิตร เพื่อทำให้เกิดการ เจือจาง 1,000 เท่า
- ในตอนท้ายคุณจะได้สารละลายที่เจือจาง 100 เท่าและเจือจาง 1,000 เท่า ใน 2 ถัง

น้ำยางเคลือบผิววัสดุแบบชั่วคราว (Filmprotector)

- เทน้ำยางออกมาจากบรรจุภัณฑ์ ลงในถังตามจำนวนที่ต้องการจะใช้
- ใช้ลูกกลิ้งจุ่มลงในถังที่แบ่งออกมา แล้วทาไปในแนวขึ้นอย่างเดียว บนบริเวณที่ต้อง การจะกำจัดรา
- รอให้น้ำยางแห้งจากนั้น ทาใหม่อีก2รอบ โดยในแต่ละรอบต้องรอให้น้ำยาแห้งสนิทก่อนเริ่มทาชั้นใหม่
- หลังจากครบสามรอบ รอให้น้ำยางแห้งให้สนิทให้ทำการลอกฟิล์มออกมา

ความปลอดภัยของสารเคมี

บอแรกซ์

- สวมถุงมือ
- ใช้บอแรกซ์ในบริเวณที่มีอากาศถ่ายเทสะดวก
- เปลี่ยนเสื้อผ้าของคุณหากบอแรกซ์สัมผัสโดนมัน ถอดเสื้อผ้าที่เปื้อนออก

ล้างมือให้สะอาดก่อนรับประทานอาหาร ดื่มน้ำ แต่งหน้า ทาเครื่องสำอาง หรือเข้า ห้องน้ำหลังใช้บอแรกซ์

- หากผงบอแรกซ์เข้าตาหรือถูกผิวหนัง ในกรณีที่สัมผัส ให้ล้างผิวหนังและดวงตา ด้วยน้ำ อย่างน้อย 15 นาที
- เริ่มการช่วยหายใจในกรณีที่หายใจเข้าโดยไม่ได้ตั้งใจ
- ขอความช่วยเหลือจากแพทย์หากจำเป็น ในกรณีที่ได้รับสาร
- โทรติดต่อศูนย์ควบคุมสารพิษและบริการฉุกเฉินอื่นๆ หากจำเป็น

เบนซาโคเนียม คลอไรด์

- หากสูดดม รีบไปพบแพทย์ทันที.
- หากถูกผิวหนังให้ถอดเสื้อผ้าที่เปื้อนออกทันที ล้างผิวหนังด้วยน้ำ/สบู่ รีบไปพบแพทย์ทันที.
- ในกรณีที่เข้าตาให้ล้างออกด้วยน้ำปริมาณมาก โทรหาจักษุแพทย์ทันที ถอดคอนแทคเลนส์ออก
- หากกลืนกิน ให้ผู้ป่วยดื่มน้ำ (อย่างมากที่สุดสองแก้ว) หลีกเลี่ยงการทำให้อาเจียน (เสี่ยงต่อการทะเล) รีบไปพบแพทย์ทันที. อย่าพยายามทำให้เป็นกลาง

น้ำยางเคลือบผิววัสดุแบบชั่วคราว (Filmprotector)

- ระหว่างที่พกลูกกลิ้งให้จมลงไปในถังน้ำยาง เพื่อป้องกันการแข็งตัวของฟิล์ม
- ไม่ควรใช้ถุงมือในระหว่างที่ทา เพราะอาจส่งผลให้ถุงมืออาจติดกับลูกกลิ้งได้

- น้ำยางมีความปลอดภัยหากติดมือสามารถลอกออกได้ แต่ไม่ควรนำเข้าปาก

วัสดุ

1. แผ่นไม้ผิวเรียบ 2 ชั้น (ราขึ้นบนพื้นผิว)
2. แปรง 4 ชั้น
3. ลูกกลิ้งทาสี 1 อัน
4. สูตร BSAC 14
5. สูตร MDP01
6. น้ำยางเคลือบผิววัสดุแบบชั่วคราว (Filmprotector)
7. ผ้าซีริวสะอาด 5 ผืน
8. ถังผสม 5 ถัง
9. กระบอกรด 20 ml 2 อัน
10. กระบอกรด 200ml 2 อัน
11. ขวดน้ำ 1.5 ลิตร 5 ขวด

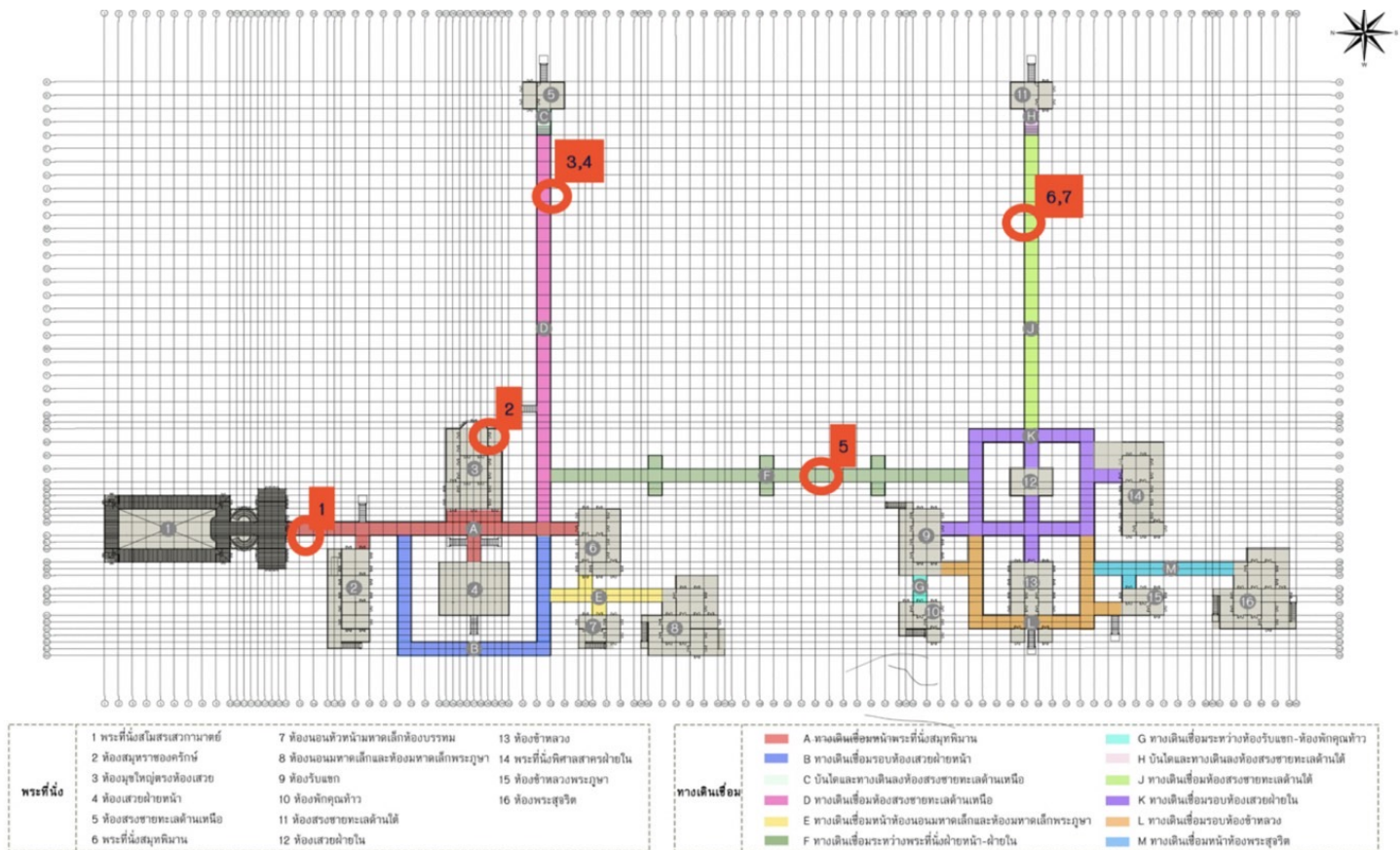
ขั้นตอนการทดลอง

สำหรับ สาร สูตร BSAC 14 และสูตร MDP01:

1. ขั้นแรก ให้ใช้ผ้าเปียกสะอาดเช็ดพื้นผิวออกก่อนลงน้ำยาโดย มี 7
พื้นที่ที่จะใช้สารในการทดสอบ
2. จากนั้น นำสูตร BSAC 14 และสูตร MDP01 ออกมา (อ่านวิธีการเตรียม ก่อนที่จะ ดำเนิน
การขั้นตอนต่อไป)
3. ใช้แปรงเพื่อทาน้ำยาแต่ละชนิดลงในโครงสร้างไม้ จากนั้นรอ 15-30 นาที เพื่อให้สาร
แห้ง

4. ทาสารซ้ำอีกครั้ง

5. สังเกตไม้สัปดาห์ละครั้งเพื่อตรวจสอบว่ารากสับมางอกใหม่หรือไม่ และบันทึกวันที่ลงในแบบตรวจสอบ



สำหรับ น้ำยางเคลือบผิววัสดุแบบชั่วคราว:

1. นำแผ่นไม้ผิวเรียบ 2 ชั้น ที่มีราขี้นบนพื้นผิว
2. เทน้ำยางออกมาจากบรรจุภัณฑ์ ลงในถังตามจำนวนที่ต้องการจะใช้
3. ใช้ลูกกลิ้งจุ่มลงในถังที่แบ่งออกมา แล้วทาไปในแนวชั้นอย่างเดียว บนแผ่นไม้ผิวเรียบ 2 ชั้น
4. รอให้น้ำยางแห้งจากนั้น ทาใหม่อีก2รอบ โดยในแต่ละรอบต้องรอให้ น้ำยาง แห้งสนิท ก่อนเริ่มทาชั้นใหม่

5. หลังจากครบสามรอบ รอให้น้ำยางแห้งให้สนิทให้ทำการลอกฟิล์มออกมา
6. สังเกตไม้สัปดาห์ละครั้งเพื่อตรวจสอบว่ารากกลับมางอกใหม่หรือไม่ และบันทึก วันที่ลงในแบบตรวจสอบ

ข้อควรระวังเพื่อความปลอดภัยในห้องปฏิบัติการ:

1. แวนดาหรืออุปกรณ์ป้องกันดวงตา
2. แมส N-95 หรือแมสที่มีการปกป้องมากยิ่งขึ้น (ตรวจสอบบรรจุภัณฑ์สำหรับ “N-95”)
3. เสื้อเชิ้ตแขนยาว
4. ถุงมือป้องกัน
5. กางเกงขายาว
6. รองเท้าบูทกันน้ำ
7. หลังจากเสร็จสิ้นการทดลองให้ล้างมือด้วยสบู่

Experimental procedure flowchart

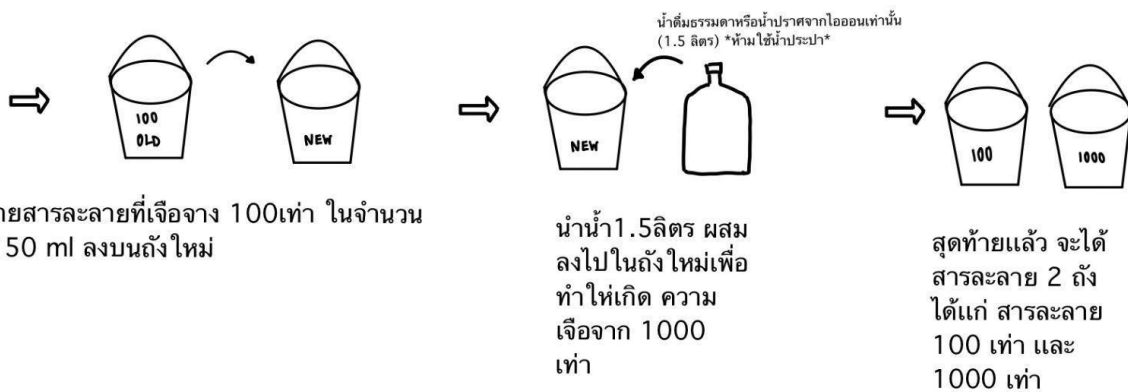


② การเตรียมสาร

2.1 สูตร BSAC 14



นำสูตร BSAC 14 จำนวน
15ml ผสมกับน้ำ 1.5ลิตร

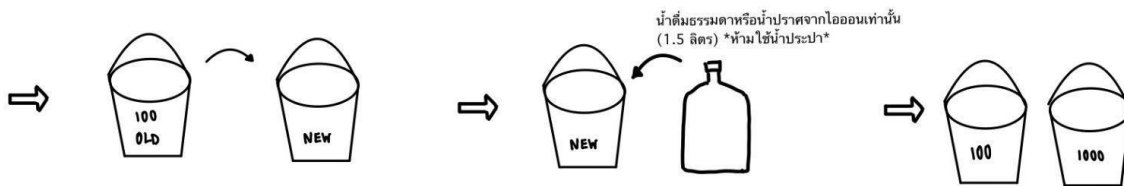


2.2 สูตร MDP01



นำสูตร MDP01 จำนวน
15ml ผสมกับน้ำ 1.5ลิตร

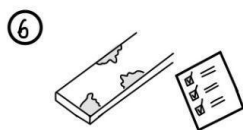
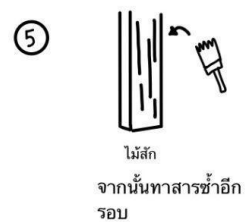
สาร MDP01
ที่เจือจาง 100เท่า



ถ่ายสารละลายที่เจือจาง 100เท่า ในจำนวน
150 ml ลงบนถังใหม่

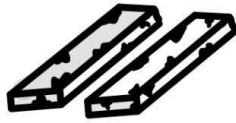
นำน้ำ 1.5ลิตร ผสม
ลงไปถังใหม่เพื่อ
ทำให้เกิด ความ
เจือจาง 1000
เท่า

สุดท้ายแล้ว จะได้
สารละลาย 2 ถัง
ได้แก่ สารละลาย
100 เท่า และ
1000 เท่า



ตรวจผิวไม้อาทิตย์ละครั้งว่ามีเชื้อราเกิดขึ้นอีกหรือไม่ แล้วบันทึกลงในแบบฟอร์ม

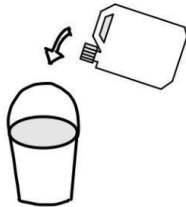
①



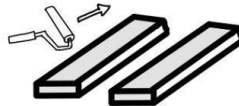
สำหรับ Filmprotector นำแผ่น
ไม้เรียบ 2 ชิ้นที่มีราขึ้นบนผิวไม้

②

ฟิล์ม โพรเทคเตอร์



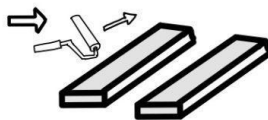
เทฟิล์ม โพรเทคเตอร์ที่
ต้องการจะใช้ลงบนถังเปล่า



จุ่มลูกกลิ้งลงบนถังที่บรรจุผลิตภัณฑ์ฟิล์มโพรเทคเตอร์และทาลง
บนผิวไม้ให้ครอบคลุมเพียงรอบเดียว



รอให้ฟิล์มแห้ง

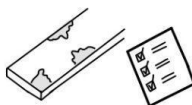


ทาใหม่อีก2รอบ โดยแต่ละ
รอบควรรอให้ตัวฟิล์มแห้ง
สนิทก่อน



หลังจากที่ทาครบ3รอบแล้ว
รอให้ฟิล์มแห้งสนิท จากนั้น ให้ลอกฟิล์มออก

③



ตรวจผิวไม้อาทิตย์ละครั้งว่ามีเชื้อราเกิดขึ้นอีก
เปล่า แล้วบันทึกลงในแบบฟอร์ม

Monitoring form

ชื่อ นามสกุล..... วันที่...../...../.....

ใบเก็บข้อมูลผลสัมฤทธิ์ของการของสารในแต่ละจุด

เก็บข้อมูลการสังเกตการอาทิตยละครึ่ง

การเก็บข้อมูลครั้งที่

จุดที่	ชื่อสาร	ผลที่ได้จากการสังเกตการกลับมาของเชื้อรา (สังเกตด้วยตาเปล่า)	รูปถ่าย (ทางเลือกเพิ่มเติม:ใช้เลนส์ขยายเพื่อความแม่นยำในการถ่ายภาพ)
1	สาร สูตร BSAC 14 ความเจือจาง 100		
1	สาร สูตร BSAC 14 ความเจือจาง 1000		

1	สาร สูตร MDP01 ความเจือจาง 100		
1	สาร สูตร MDP01 ความเจือจาง 1000		
2	สาร สูตร BSAC 14 ความเจือจาง 100		
2	สาร สูตร BSAC 14 ความเจือจาง 1000		
2	สาร สูตร MDP01 ความเจือจาง 100		
2	สาร สูตร MDP01 ความเจือจาง 1000		

3	สาร สูตร BSAC 14 ความเจือจาง 100		
3	สาร สูตร BSAC 14 ความเจือจาง 1000		
3	สาร สูตร MDP01 ความเจือจาง 100		
3	สาร สูตร MDP01 ความเจือจาง 1000		
4	สาร สูตร BSAC 14 ความเจือจาง 100		
4	สาร สูตร BSAC 14 ความเจือจาง 1000		

4	สาร สูตร MDP01 ความเจือจาง 100		
4	สาร สูตร MDP01 ความเจือจาง 1000		
5	สาร สูตร BSAC 14 ความเจือจาง 100		
5	สาร สูตร BSAC 14 ความเจือจาง 1000		
5	สาร สูตร MDP01 ความเจือจาง 100		
5	สาร สูตร MDP01 ความเจือจาง 1000		

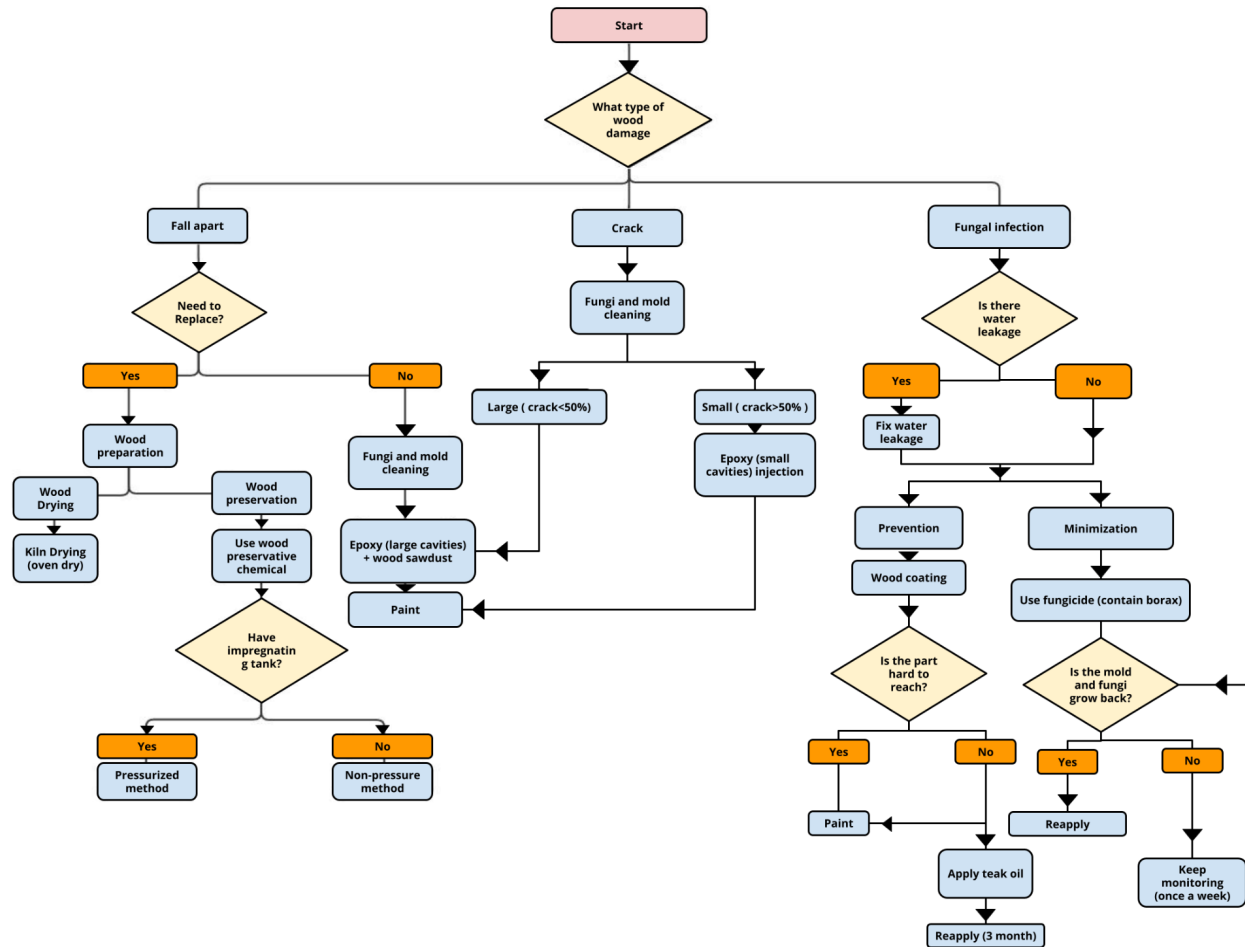
6	สาร สูตร BSAC 14 ความเจือจาง 100		
6	สาร สูตร BSAC 14 ความเจือจาง 1000		
6	สาร สูตร MDP01 ความเจือจาง 100		
6	สาร สูตร MDP01 ความเจือจาง 1000		
7	สาร สูตร BSAC 14 ความเจือจาง 100		
7	สาร สูตร BSAC 14 ความเจือจาง 1000		

7	สาร สูตร MDP01 ความเจือจาง 100		
7	สาร สูตร MDP01 ความเจือจาง 1000		

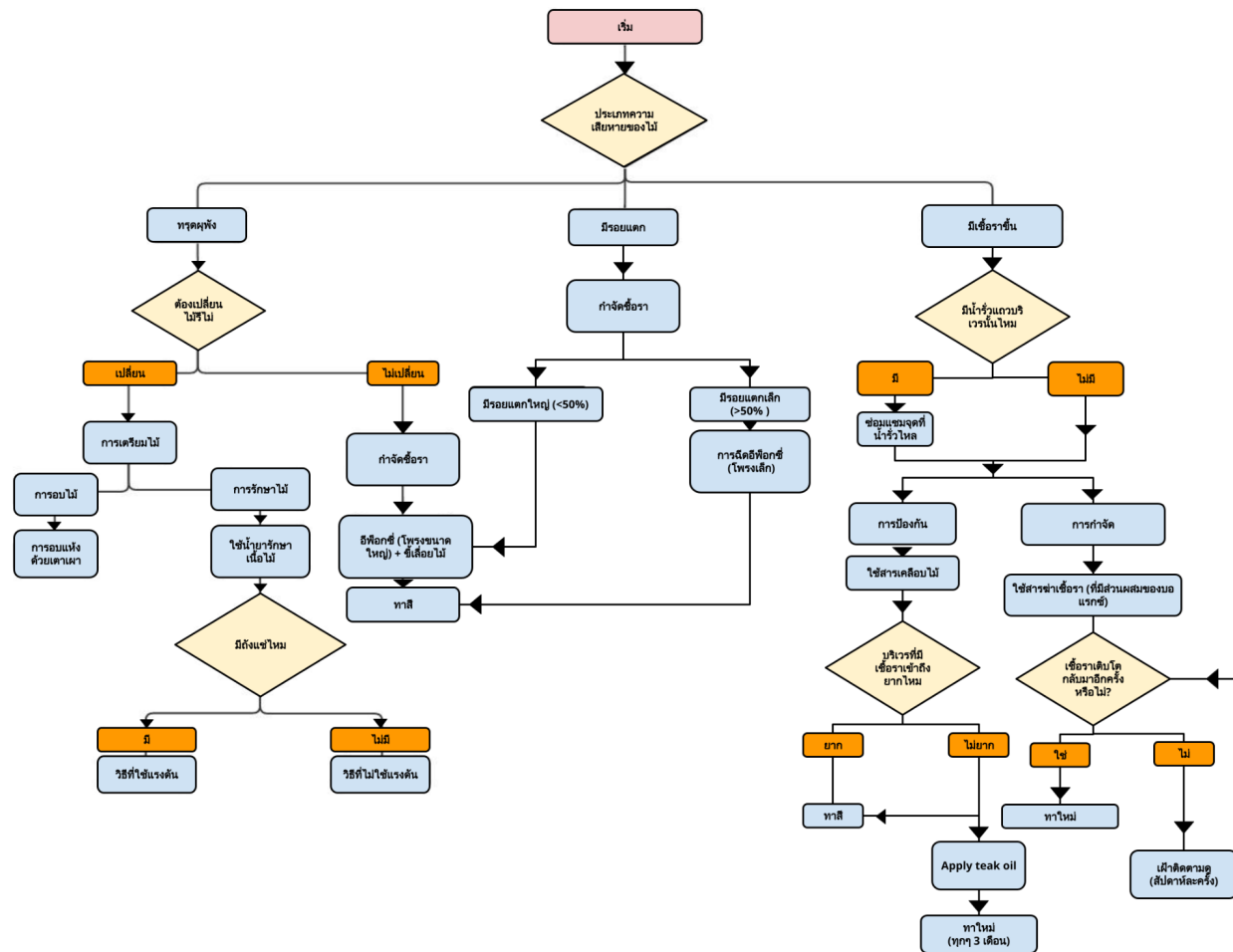
ไม้	ข้อสาร	ผลที่ได้จากการสังเกตดูการกลับมา ของเชื้อรา (สังเกตด้วยตาเปล่า)	รูปถ่าย (ทางเลือกเพิ่มเติม: ใช้เลนส์ขยาย เพื่อความแม่นยำในการถ่ายภาพ)
1	Filmprotector		
2	Filmprotector		

Appendix I - Decision tree

The decision tree is to help the Mrigadayavan Palace Foundation choose suitable actions for each type of wood damage.



แผนผังเพื่อช่วยเลือกการดำเนินการที่เหมาะสมเมื่อเผชิญกับความเสียหายของไม้แต่ละประเภท



Appendix J - Wood Preservative Chemical From [ISSP BSAC \(2021\)](#)

This table lists out the wood preservative chemicals that the past ISSP team have recommended to the Mrigadayavan Palace.

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)