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BACHELOR OF SCIENCE IN APPLIED CHEMISTRY



**WPI**



พระราชวังมฤคทายวัน  
MRIGADAYAVAN PALACE  
英威陶麗宮

**IQPISSP3**

# Restoring Mrigadayavan Palace: Understanding Causes of Concrete Deterioration and Determining Viable Concrete Rehabilitation Methods

## Sponsor:

Mrigadayavan Palace Foundation

## Researchers:

Megan Cyr<sup>2</sup>, Pimsucha Kanjchanapoomi<sup>1</sup>, Tovah Lockwood<sup>2</sup>, Alyssa Magaha<sup>2</sup>,  
Natwara Manitsirisuk<sup>1</sup>, Anne McNamara<sup>2</sup>, Krittin Thasunthorn<sup>1</sup>, Poom Ungolan<sup>1</sup>

## Advisors:

Assoc. Prof. Holly K. Ault<sup>2</sup>, Assist. Prof. Dr. Numpon Insin<sup>1</sup>, Assist. Prof. M.L. Siripastr Jayanta<sup>1</sup>,  
Assoc. Prof. Stephan Sturm<sup>2</sup>, Prof. Dr. Supawan Tantayanon<sup>1</sup>

<sup>1</sup> Department of Chemistry, Faculty of Science, Chulalongkorn University, Bangkok, Thailand

<sup>2</sup> Worcester Polytechnic Institute, 100 Institute Rd, Worcester, MA, USA

## Team Members



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**Krittin  
Thasunthorn  
(Blue)**



**Natwara  
Manitsirisuk  
(Bam)**



**Pimsucha  
Kanjchanapoomi  
(Jubu)**



**Poom  
Ungolan  
(Poom)**



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**Megan Cyr**



**Anne McNamara**



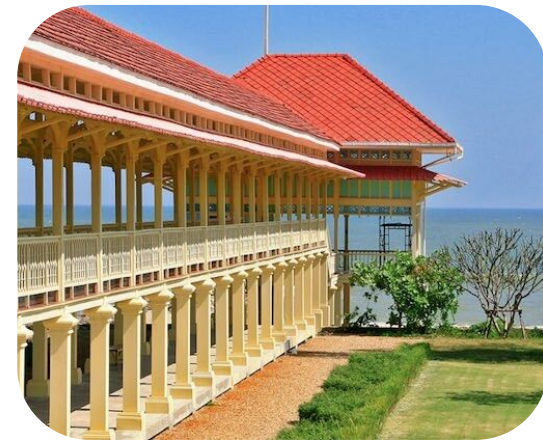
**Alyssa Magaha**



**Tovah Lockwood**

# The Mrigadayavan Palace

Cha-am,  
Phetchaburi



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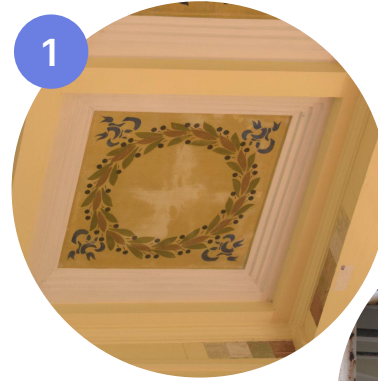
## The Problem



Three structures of the palace  
concrete are deteriorating

1

Concrete  
Ceiling  
Panels



2

Concrete  
Columns



3

Concrete  
Walkways



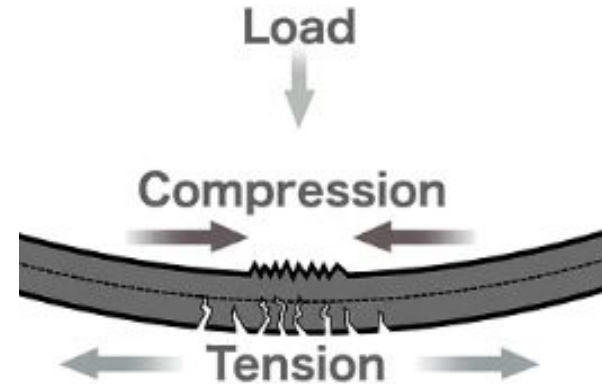
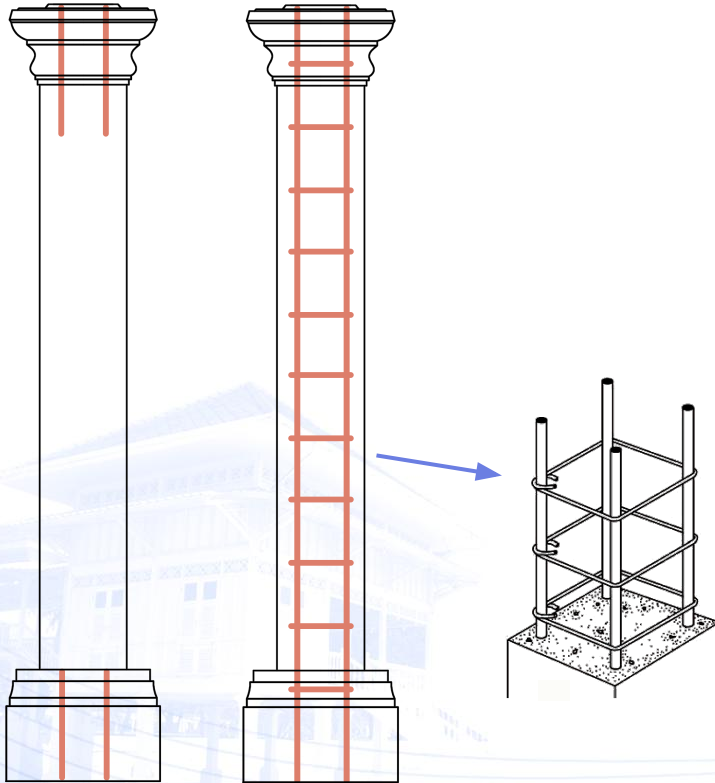




# Background

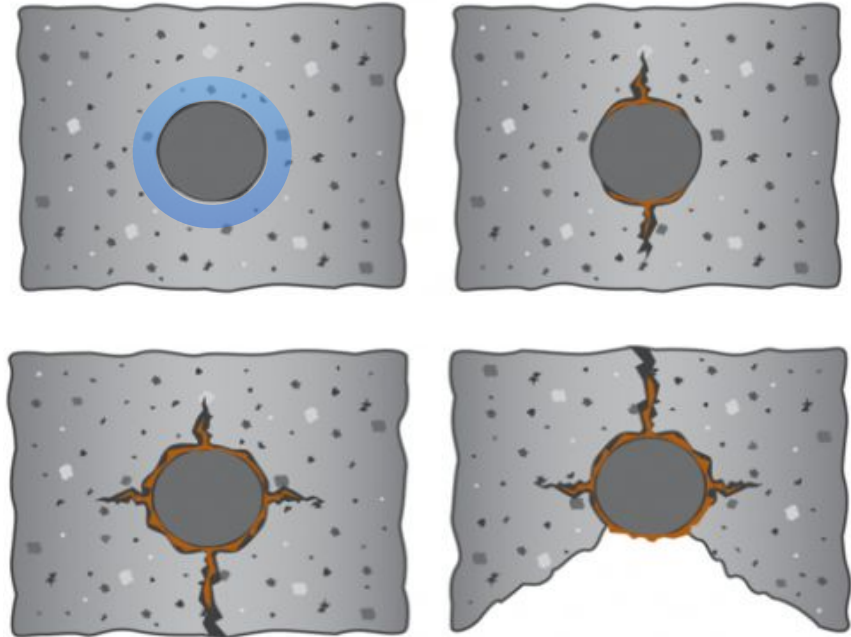


# Steel reinforcement increases tensile strength in concrete





The chemical deterioration  
of steel reinforced concrete  
leads to physical damage







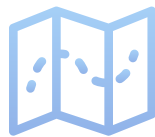
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吳厝廟聖宮



# Methodology

# Objectives



## 1. Assessing deterioration extent & causes

- Interview staff
- Qualitative observations
- Quantitative observations



## 2. Analyzing viable restoration methods

- Consult restorations from other case studies
- Conduct literature review

## Objectives



### 3. Creating a decision tree for restoration

- Develop a supplemental table
- Analyze methods based on criteria



### 4. Developing educational content

- Display findings on the Palace website
- Create QR codes and pamphlets





# Findings & Analysis

# 1. Concrete Columns



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## Cracks can be categorized in two ways

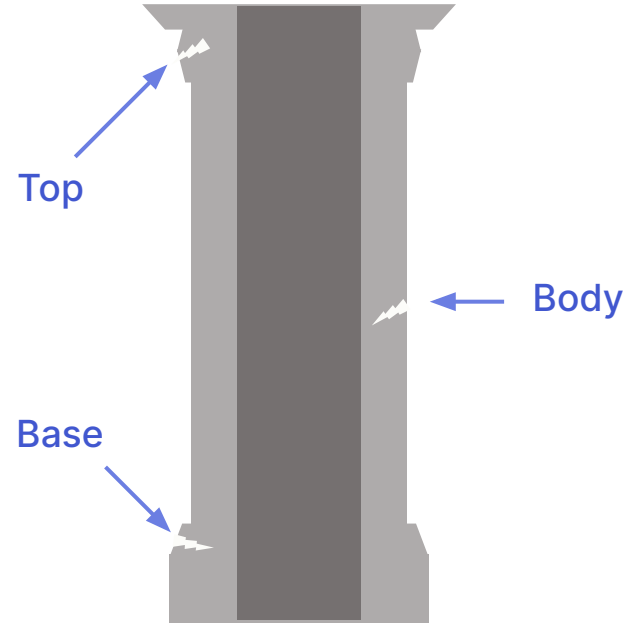


Vertical  
Crack



Horizontal  
Crack

### Patterns of Cracks

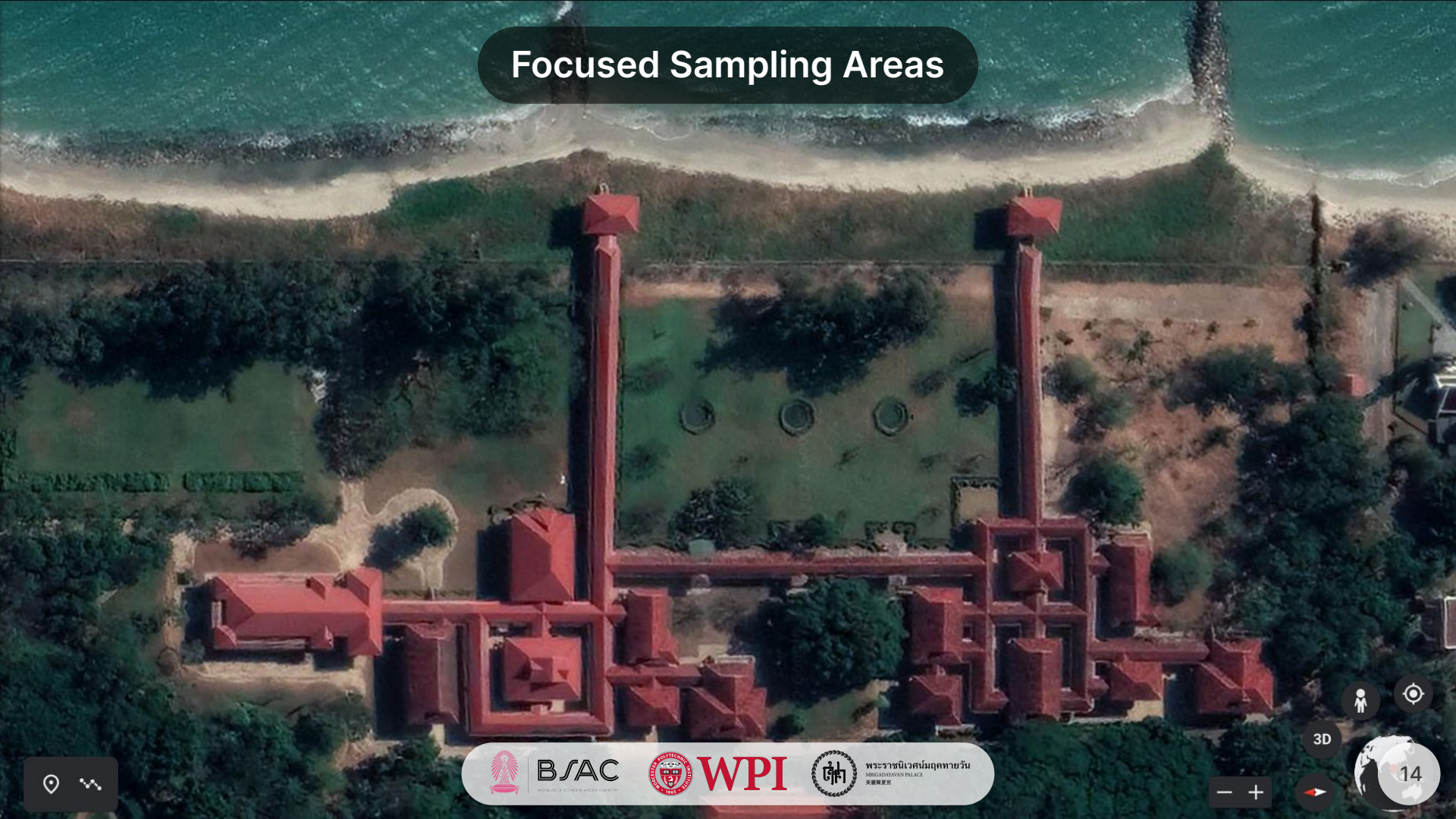


### Location of Cracks





# Focused Sampling Areas



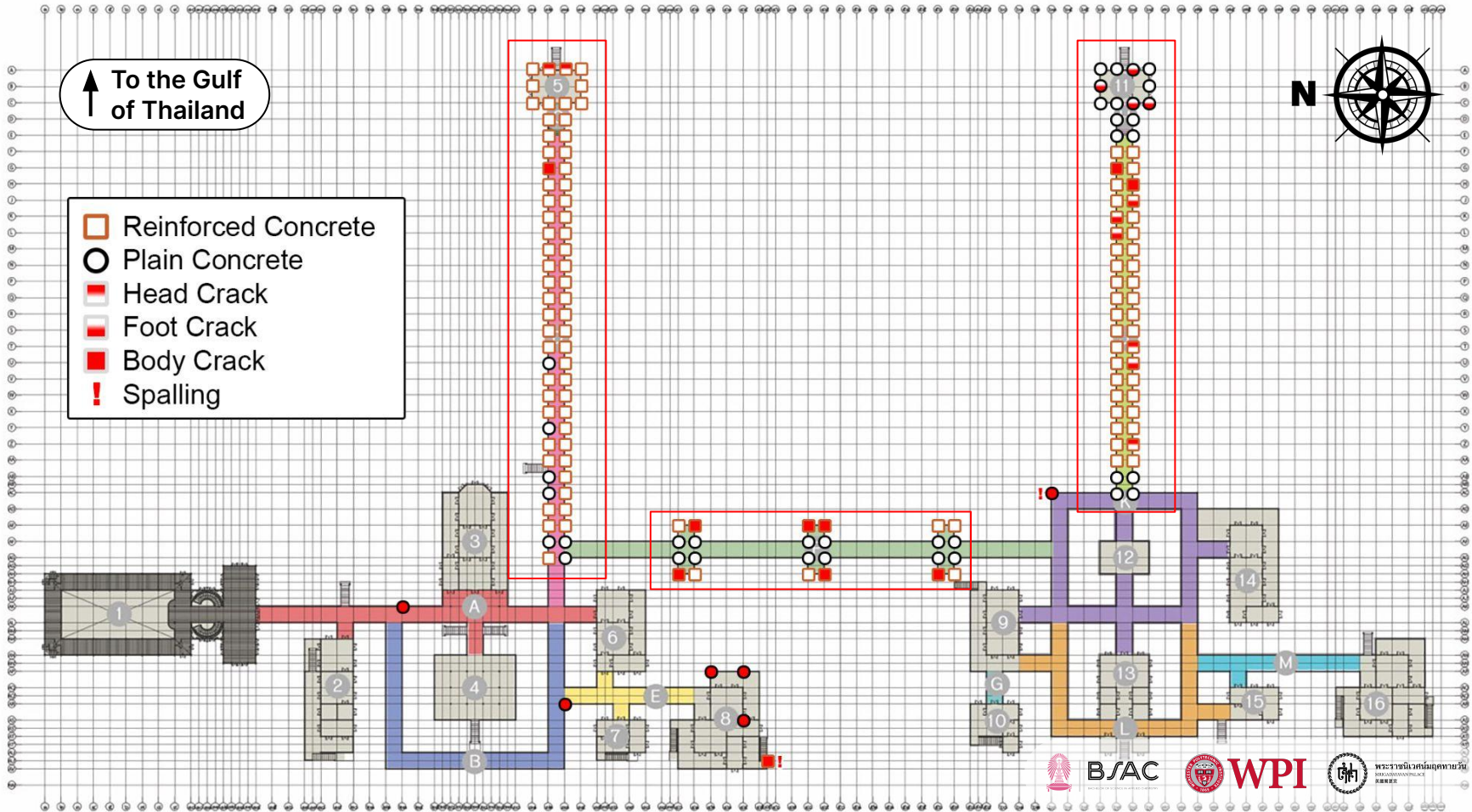
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WATSON PEARL INSTITUTE

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MHRUADAYAN PALACE  
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# Focused Sampling Areas

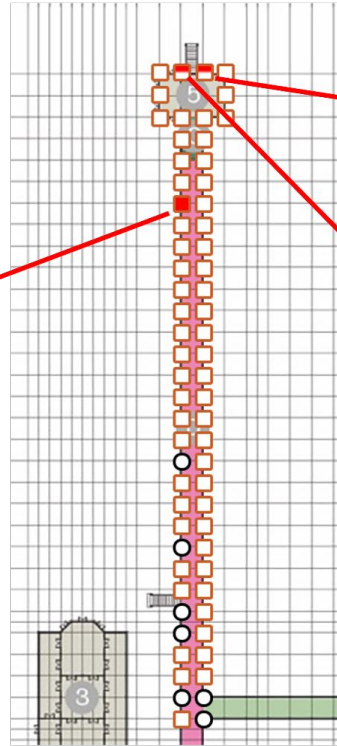
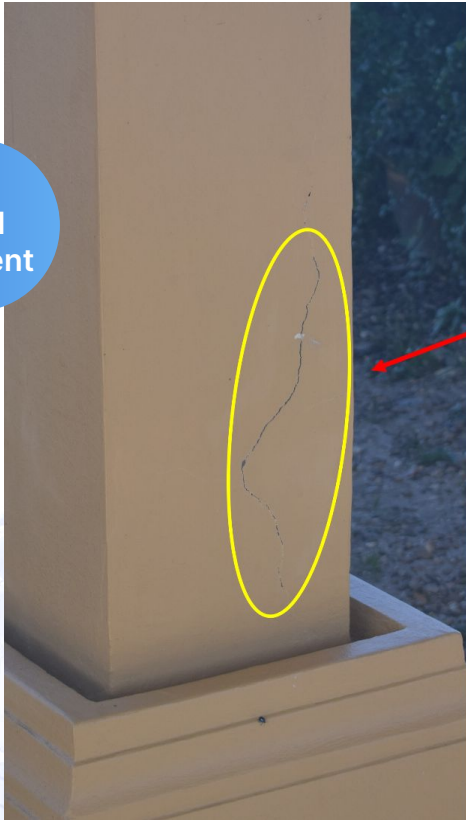




# Concrete Columns

## Outer Court Bathing Pavilion (North Side)

89.4%  
have steel  
reinforcement

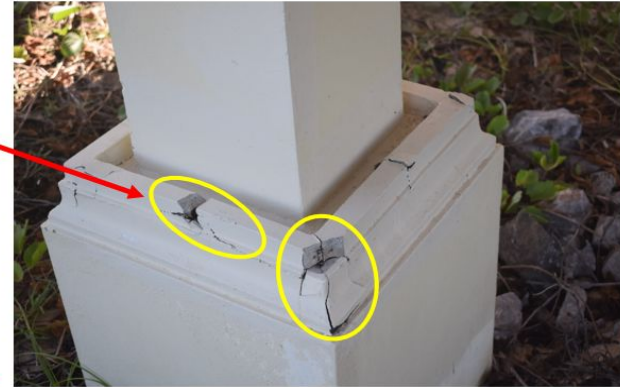
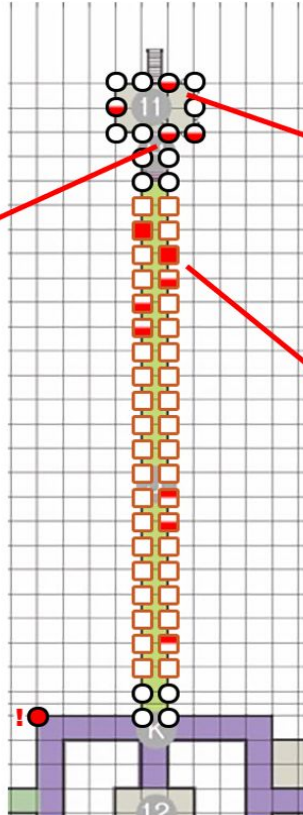


# Concrete Columns

## Inner Court Bathing Pavilion (South Side)

69%  
have steel  
reinforcement

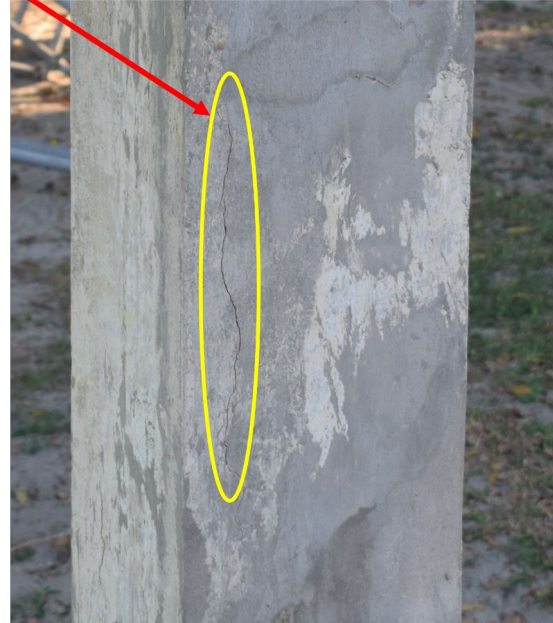
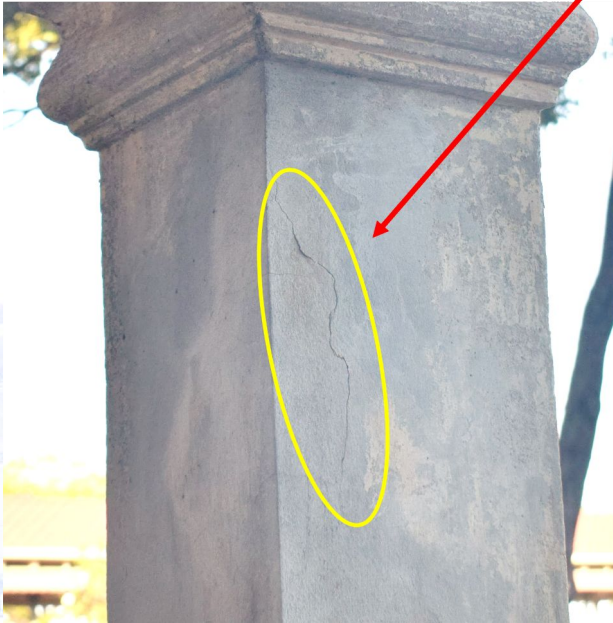
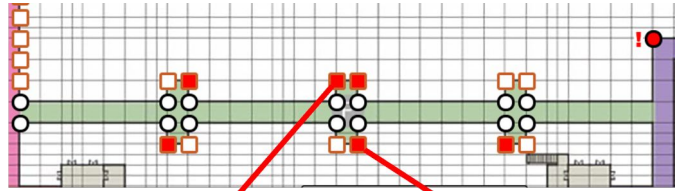
20.7%  
have cracks





# Concrete Columns

## Linking Corridor Between the Two Courts





# Improper repairs, wind, and location cause deterioration

01

Additional Patched Layer

Crack

### Improper Repairs

Insufficient surface preparation for patched layer of concrete

02

Lateral load

### Effect of Wind

Strong winds add lateral loads that increases tension

03

Cl<sup>-</sup> CO<sub>2</sub> Moisture

Chlorinated/Carbonated Concrete

Rust

Reinforcement

### Seaside Location

Exposure to humidity from environment and sea-spray



## 2. Concrete Walkways



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## Concrete Walkways

**Observation:** Previous restoration techniques have failed



Cracks in the concrete walkways  
between two columns



Cracks above the patched concrete layer



## Concrete Walkways

Causes of cracks on concrete walkways include the **absence of expansion joints** and **usage over time**



Example of Expansion Joints



Mechanical Usage of Walkways



### 3. Concrete Ceiling Panels



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吳實業堂



## Concrete Ceiling Panels

### Cracks

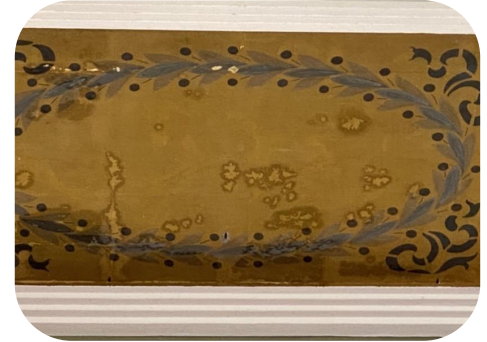


Small cracks in the middle between two edges

### Discoloration



A pale plus sign mark in the middle

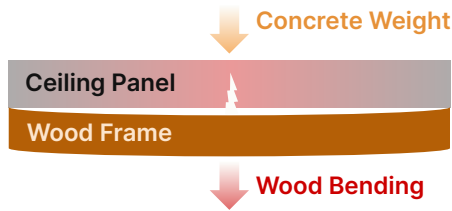


Pale marks with a droplet-like shape



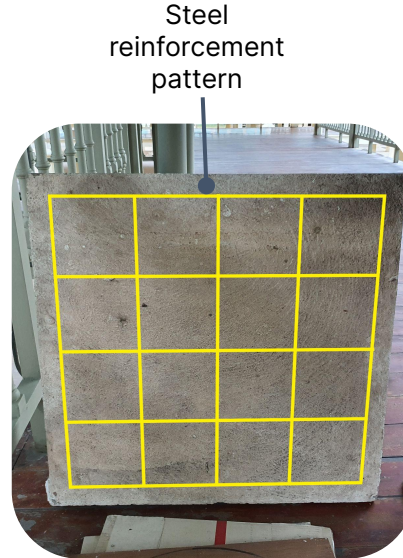
# Two causes of ceiling panels deterioration are determined

## Cracks

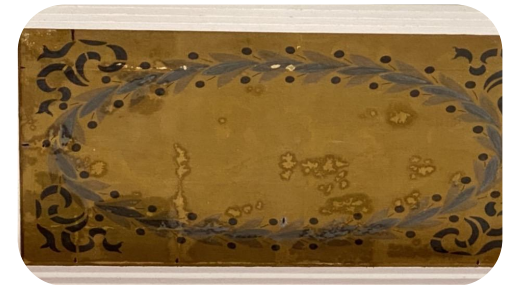
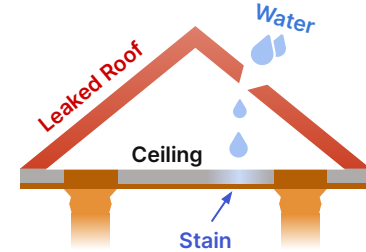


An unstable **wood framework** causes cracks in concrete

## Discoloration



**Humidity** causes rust on steel rebar



**Roof leakage** causes discoloration





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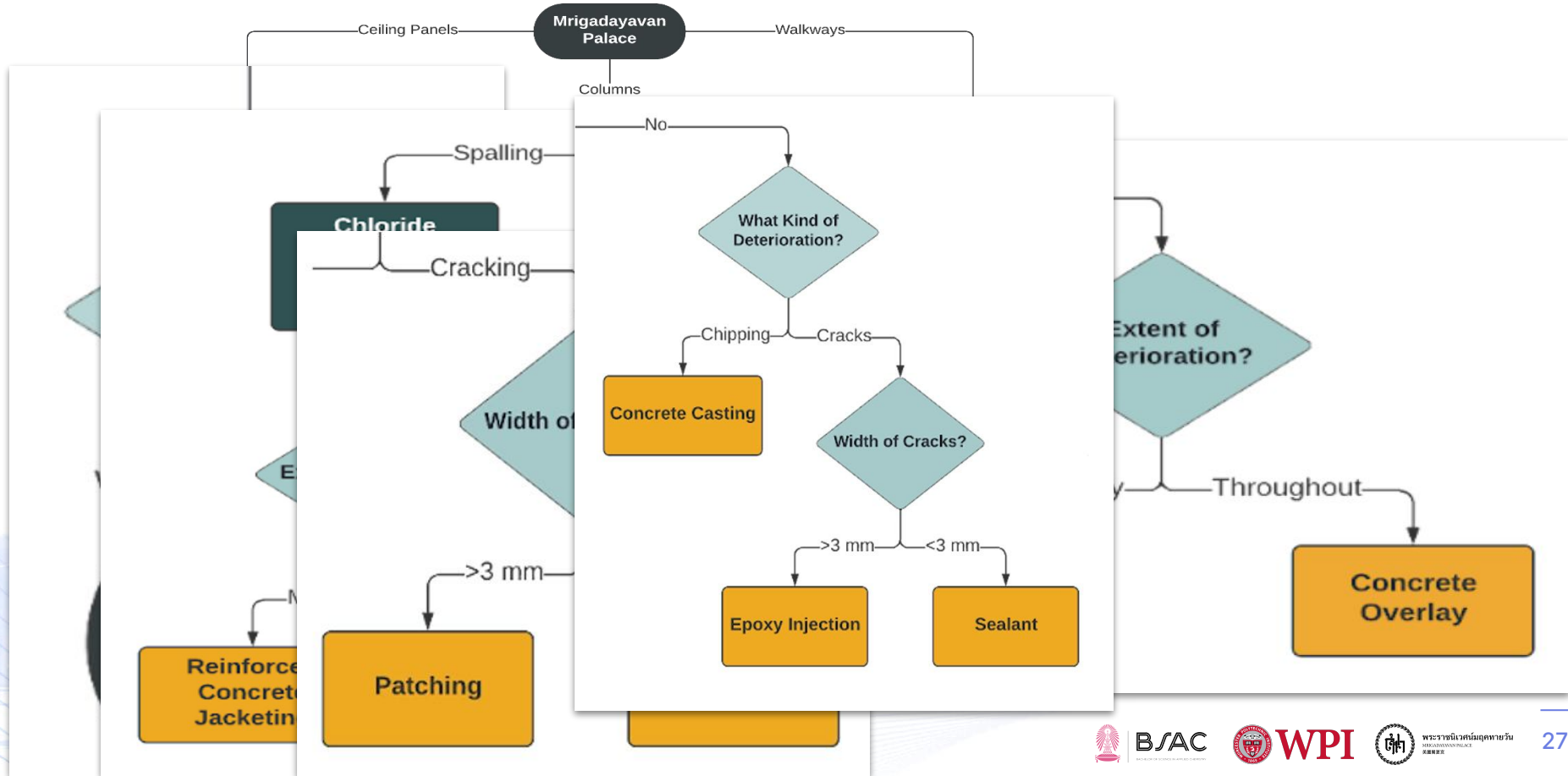
พระราชินีวิเทศน์อุตสาหกรรม  
ARACHINWITSAKARN  
吴麗麗更立



# Recommendations



# The decision tree will help the sponsors choose the best repair technique for each deterioration





# Deliverables

Website



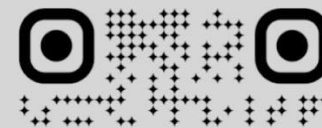


# เรียนรู้เพิ่มเติม ออนไลน์!

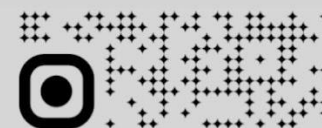
ต้องการเรียนรู้เพิ่มเติมเกี่ยวกับการ  
บูรณะคอนกรีต? สแกน QR code เพื่อ  
เข้าชมเว็บไซต์พระราชนิเวศน์  
มฤคทายวันเพื่อดูข้อมูลเพิ่มเติม!



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ที่ว่าง QR code



พื้นที่ว่าง

เนื้อหาใด ๆ ในส่วนนี้ของหน้าจะ  
ถูกรอบคลุมโดย QR code  
รหัสจริงจะได้รับการสรุปหลังจากขั้นตอน  
การออกแบบ

# กระบวนการวิจัย

ประกอบไปด้วยขั้นตอนต่อไปนี้



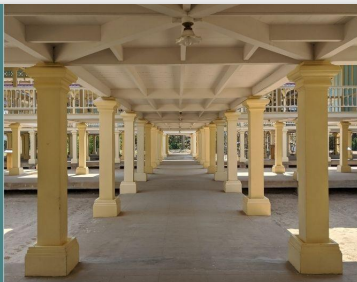
การประเมินความเสี่ยง



การเลือกวิธีการบูรณะ



การบูรณะเสาคอนกรีต



”

## อะไรคือวิธีที่เหมาะสมมากที่สุด?

### การประสานรอยร้าวโดยอัดฉีดน้ำยาอีพ็อกซี่

การอัดฉีดน้ำยาอีพ็อกซี่ถูกใช้สำหรับการซ่อมแซมและบูรณะเสาคอนกรีตรูปแบบดังกล่าว เนื่องจากเสาดังกล่าวเป็นเสาประเภทคอนกรีตเสริมเหล็ก

## มีเสาคอนกรีตเสื่อมสภาพประมาณ 30 %

เสาประมาณ 250 ต้นมีการเสื่อมสภาพและชำรุดจากการการแตกร้าวและการหลุดร่อนของคอนกรีต



## Acknowledgements

### Sponsor



**Director of the Mrigadayavan Palace Foundation**  
Klaomard Yipintsoi

**Archaeologist**  
Erbprem Vatcharangkul

### WPI Advisors



Adj. Prof. Dr. Holly Ault  
Assoc. Prof. Dr. Stephan Sturm

### BSAC Advisors



Assist. Prof. Dr. Numpon Insin  
Assist. Prof. M.L. Siripastr Jayanta  
Prof. Dr. Supawan Tantayanon





Thank you

Any questions or comments?



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美羅廟宮堂

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[gr-bkkc22-palace@wpi.edu](mailto:gr-bkkc22-palace@wpi.edu) (WPI)

for any questions, comments, or suggestions

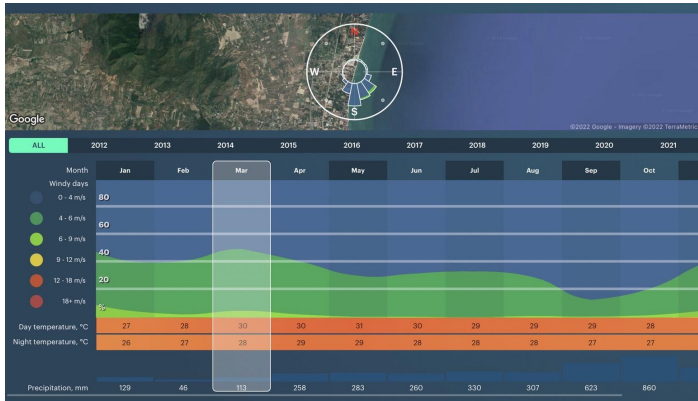




January



February



March



April

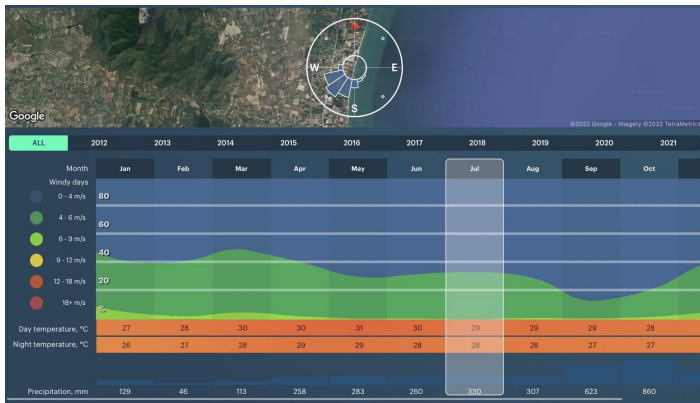




May



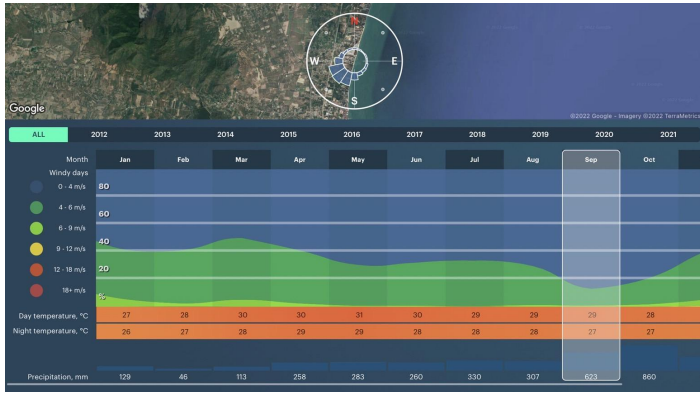
June



July



August



September



October



November



December







## Friday Outline (15 min)

- Opening & Team Members Introduction (30 seconds) (Blue)
- Introduction
  - Mrigadayavan Palace (30 seconds) (Blue)
  - Sponsor & Restoration Project (30 seconds) (Blue)
  - Architecture of Mrigadayavan Palace (-)
  - The Problem **& Goal of The Project** (1 min) **(Anne)**
- Background (2 min)
  - Defining Technical Terms (Tovah)
  - Concrete Background (Megan)
- Objectives & Methodology (1.5 min) (Anne)
- Findings & Analysis
  - Concrete Columns (2 min) / (Poom)
  - Concrete Walkways (1.5 min) (Jubu)
  - Concrete Ceiling Panels (1.5 min)(Bam)
- Recommendations
  - Decision Tree (2 minutes) (Tovah)
- Deliverables
  - Website (30 seconds) (Alyssa)
  - QR Code & Pamphlets for Exhibition (30 seconds) (Alyssa) (both thai and english versions)
- Acknowledge experts, sponsors, and advisors (45 seconds) (Megan)

## Sponsor Saturday Outline

- Opening & Team Members Introduction
- Introduction
  - The Problem
  - Goal of The Project
- Objectives
- Methodology
- Findings & Analysis
  - Concrete Columns
  - Concrete Walkways
  - Concrete Ceiling Panels
- Recommendations
  - Decision Tree
  - Recommendation Methods Debrief Slide
- Deliverables
  - Website
  - QR Code & Pamphlets for Exhibition
- Acknowledge experts, sponsors, and advisors





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# Break Section

01:00pm ~ 01:30pm

# Photo Display



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## Break Section



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# Architecture

## Features



Roof Tiles

Concrete Ceiling Panels

Wooden Buildings,  
Columns, and Walkways

Concrete Columns

Concrete Floor Base



## The Problem

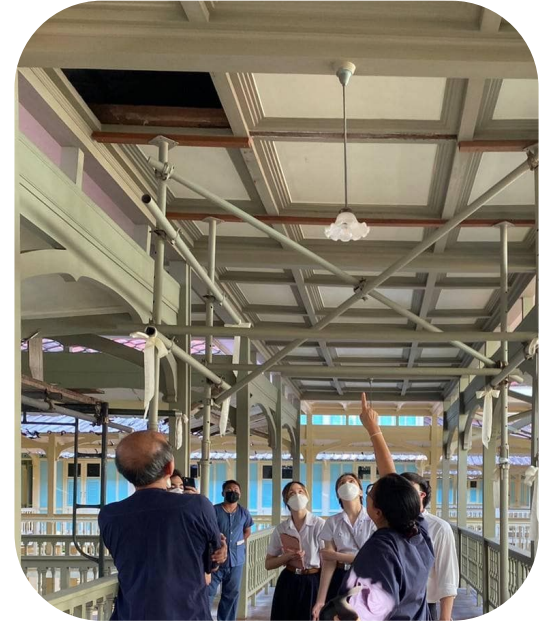
Three structures of palace concrete are deteriorating



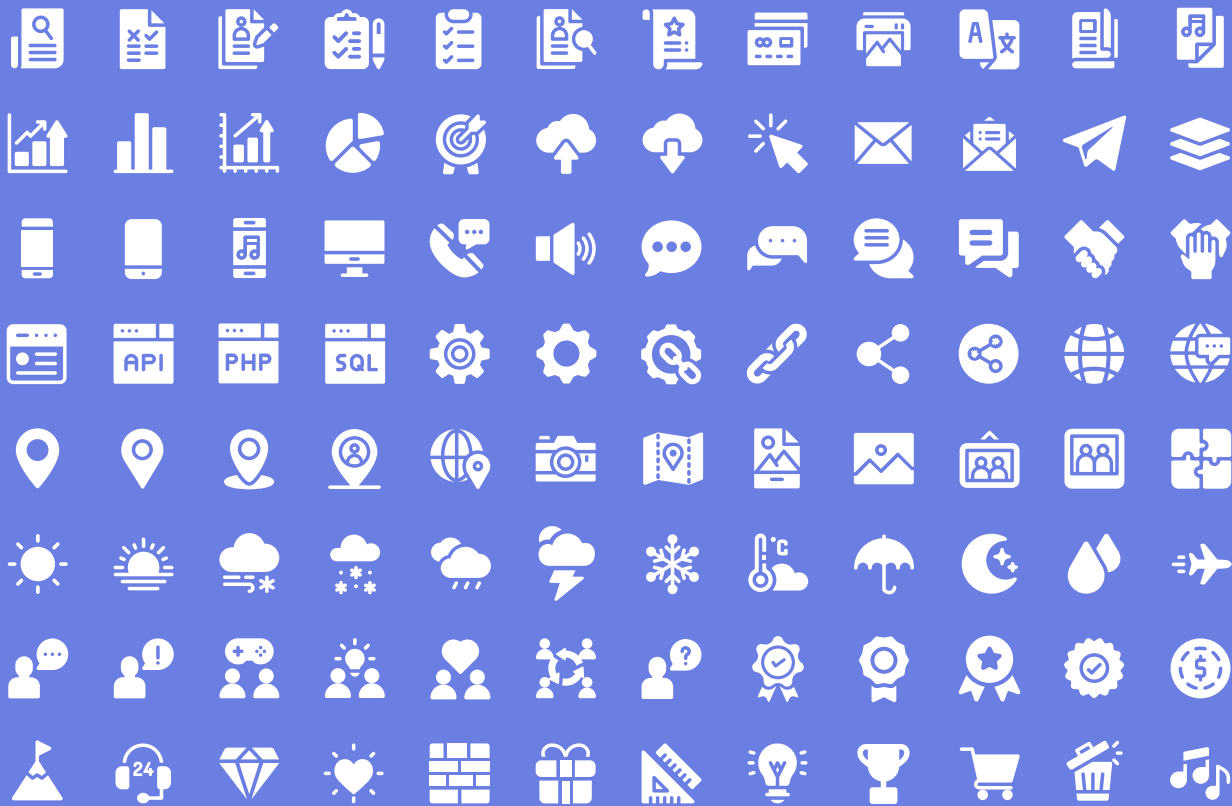
Concrete  
Column



Concrete  
Floor Base



Concrete  
Ceiling Panel



## Icon

You can resize these icons keeping the quality.

You can change the stroke and fill color; just select the icon and click on the paint bucket/pen.



## Icon

You can resize these icons keeping the quality.

You can change the stroke and fill color; just select the icon and click on the paint bucket/pen.