BIOTIC AND ABIOTIC FACTORS AFFECTING DETERIORATION OF CHUDHADHUJ PALACE MUSEUM

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ปัจจัยทางชีวภาพและกายภาพที่มีผลต่อการเสื่อมสภาพของพิพิธภัณฑ์พระจุฑาธุชราชฐาน

สิรินารี เงินเจริญ

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
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งานวิจัยนี้ ดำเนินการที่พิพิธภัณฑ์พระจุฑาธุชราชฐาน เกาะสีชัง จ.ชลบุรี โดยศึกษาการเสื่อมสภาพของพิพิธภัณฑ์พระจุฑาธุชราชฐานที่เกิดจากปัจจัยสิ่งแวดล้อมทางกายภาพและชีวภาพ

ในส่วนของปัจจัยกายภาพ ได้ศึกษาพัฒนาวิธีการตรวจวัดค่าความเข้มแสงที่ตกกระทบวัตถุโดยพัฒนาแบบจำลอง ด้วยการปรับค่าคงที่ให้สอดคล้องกับลักษณะเฉพาะถิ่น พบว่าวิธีนี้สามารถนำไปวิเคราะห์ค่าความเข้มแสงที่ตกกระทบวัตถุ ประเมินและคาดคะเนระดับการเสื่อมสภาพที่เกิดขึ้นกับวัตถุได้ผลดี และน่าเชื่อถืออย่างมีนัยสำคัญ ทั้งนี้เมื่อใช้ค่าคงที่ความเข้มแสงสองแหล่งได้แก่ ค่าความเข้มแสงจากดวงอาทิตย์และจากการกระเจิงของท้องฟ้าเท่ากับ 2 และ 0.5 ตามลำดับ และเมื่อนำวิธีการตรวจวัดค่าความเข้มแสงด้วยแบบจำลองที่พัฒนาแล้ว ไปศึกษาการเสื่อมสภาพของศิลาจารึก ซึ่งตั้งอยู่โดยรอบวัดอัษฎางคนิมิตรและพื้นผิวปูนภายนอกของเรือนอภิรมย์ ผลจากการศึกษากับศิลาจารึก พบว่าการเสื่อมสภาพของศิลาจารึกมีความสัมพันธ์กับระดับความเข้มแสง หรืออุณหภูมิ รวมทั้งช่วงเวลาที่แสงตกกระทบ สามารถจำแนกระดับการเสื่อมสภาพของศิลาจารึกได้ 3 กลุ่ม คือ กลุ่มที่มีค่าระดับการเสื่อมสภาพอยู่ในช่วง 0.95 - 1, 0.695 - 0.703 และ 0.531 - 0.537 อย่างไรก็ตามวิธีการตรวจวัดดังกล่าวจะถูกต้อง ให้ผลแม่นยำ น่าเชื่อถือมากขึ้น ถ้าพัฒนาด้วยการประมวลผลร่วมกับปัจจัยสิ่งแวดล้อมที่เกี่ยวข้องอื่นๆ ต่อไป นอกจากนี้การเสื่อมสภาพของศิลาจารึกที่เกิดขึ้นนั้นมีความเกี่ยวข้องกับความเค็มจากน้ำทะเลอีกด้วย สำหรับการศึกษาผนังปูนภายนอกของเรือนอภิรมย์นั้น พบว่าการเสื่อมสภาพที่เกิดขึ้นสัมพันธ์กับความชื้นและความเข้มแสง บริเวณผนังปูนที่ได้รับความชื้นมาก และรับความเข้มแสงต่ำจะมีการเสื่อมสภาพมากที่สุด

การศึกษาการเสื่อมสภาพในพิพิธภัณฑ์พระจุฑาธุชราชฐานยังพบด้วยว่าปัจจัยชีวภาพมีผลต่อการเสื่อมสภาพหลายประการ ปัญหาสำคัญที่ก่อให้เกิดการเสื่อมสภาพดังกล่าว ได้แก่ การสร้างรังของแมลงบนพื้นผิวปูน มูลของนกและสัตว์เลื้อยคลาน รวมทั้งการเจริญเติบโตของเชื้อรา โดยในส่วนการเสื่อมสภาพจากเชื้อราบนพื้นผิวปูนนั้น พบว่า สารกันน้ำบนผนังปูนช่วยลดความรุนแรงของปัญหาการเสื่อมสภาพจากเชื้อราได้อย่างมีประสิทธิภาพ

สาขาวิชา วิทยาศาสตร์สิ่งแวดล้อม ลายมือชื่อนิสิต ....

ปีการศึกษา 2551 ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก ....

ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์ร่วม ....

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KEY WORDS : BIOTIC FACTOR / ABIOTIC FACTOR / DETERIORATION / PALACE / MUSEUM / CHUDHADHUJ

SIRINAREE NGENCHAROEN : BIOTIC AND ABIOTIC FACTORS AFFECTING DETERIORATION OF CHUDHADHUJ PALACE MUSEUM. THESIS ADVISOR : ASST. PROF. DUANGKHAE SITTICHAROENCHAI, Ph.D., CO - ADVISOR : ASSOC. PROF. ROJ KHUN - ANAKE, 182 pp.

This study was carried out at Chudhadhuj palace museum which situated at Sichang Island. It was concentrated on the study of deterioration caused by abiotic factor and biotic factor affecting on Chudhadhuj palace museum.

To estimate the light intensity rendering on the objects, a simulated model was developed. The developed model was significantly workable and reliable for analyzing the light intensity and predicting the degree of the deterioration of the target object. Sunlight intensity and sky illumination, with the value 2 and 0.5 respectively, were found to be the appropriated factors of spatial - temporal analysis. In addition, this simulated model was tested to study the deterioration of the historical stone inscriptions situated around Aussadangkhanimit Temple. The results indicated that the degradation of the stone inscriptions related to sunlight intensity and duration of light exposure.The historical stone inscriptions were categorized into 3 groups by weathering degree values, 0.95 -1, 0.695 - 0.703 and 0.531 - 0.537. However, the developed method needs more research for the better results by integrating the other physical factors involved with the deterioration. Furthermore, the deterioration was involved with salt aerosol from the sea. Additionally, this simulated model was used to study the deterioration of lime plaster surfaces on the walls outside Apirom residence. The results revealed that the degradation also related to humidity and light intensity of the plaster surfaces. The surfaces with high humidity and low light intensity rendering obtained high deterioration degree.

The study on biodeterioration at Chudhadhuj palace museum showed that there were a lot of biotic factors concerned on the degradating damages. The significant biodeterioration characteristics found on lime plasters were nests of insects, excrement of birds and reptiles, and fungus stains. Moreover, the study suggested that water repellent could be used to decrease this deterioration problem.

Field of Study Environmental Science Student's Signature

Academic Year 2008 Advisor's Signature

Co-Advisor's Signature

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CHAPTER I

INTRODUCTION

Deterioration is the process of growing worse, or the state of something develop into a bad or worse situation (Longman, 2006; Wiktionary, 2008). Its process is the gradual decline in quality of an object or situation (The British Postal Museum & Archive, n.d.). Nowadays, it was found that our cultural heritage is being destroyed. An undertstanding of the basic processes causing deterioration of ancient artifacts is urgently needed (Burns, 1991). Likewise, the Chudhadhuj palace museum is one of cultural heritage which confronted with the severe deterioration problems.

Chudhadhuj palace museum is a valuable heritage. Its area is 236 Rai. It is located at Sichang island or Koh Sichang, that is a large-sized island with the area about 18 square - kilometres or 11,250 Rai approximately (The Department of Environmental Quality Promotion, 2002). Sichang island is situated in the Gulf of Thailand, about 12 kilometres away from the western shore of Si Racha district in Chonburi Province, the depth of sea around the island is 10.8 - 18 metres (The Land Development Department, 2000).

As a consequence of the location of Chudhadhuj palace museum, it was presumed that the palace museum deterioration problems have been enhancing by both biotic and abiotic factors of the marine environment, such as light intensity, humidity, sea aerosol, microorganism and animals. To approve these hypothesis hence this study was carried out to study abiotic and biotic factors affecting the deterioration of Chudhadhuj palace museum.

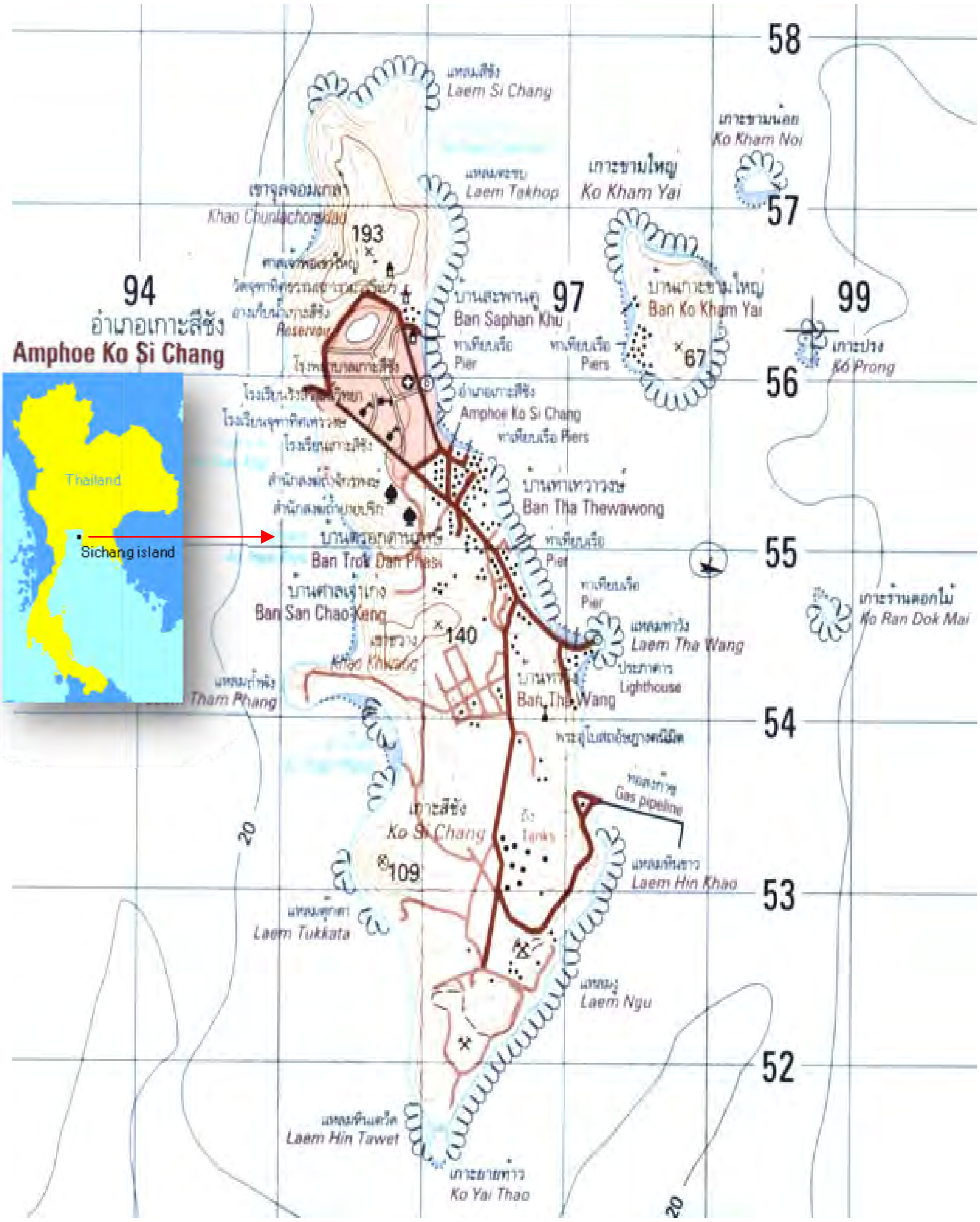


Figure 1.1 Sichang Island map (Royal Thai Survey Department, 2007)

This study had been undertaken for 15 months from June, 2007 to Apirl, 2009. Five of the buildings in the palace museum were studied namely, Green wooden residence, Wattana residence, Phongsri residence, Apirom residence and Aussadangkhanimit Temple (Figure 1.2, 1.3). The research is not only focused on the heritage material deterioration, such as lime plaster but also on historical stone inscriptions.

Figure 1.2 Chudhadhuj palace museum map (Cultural Center of Chulalongkorn University, 2006)

a. b.

c. d.

e. f.

Figure 1.3 Some parts of Chudhadhuj royal palace museum : a. Aussadangkhanimit bridge b. Phongsri residence c. Green wooden residence d. Wattana residence e. Apirom residence and f. Aussadangkhanimit Temple

CHAPTER Π

LITERATURE REVIEW

2.1 Cultural heritage

Cultural heritage (“ national heritage ” or just as “ heritage ”) is the legacy of physical artifacts and intangible attributes of a group or society that are inherited from past generations, maintained in the present and bestowed for the benefit of future generations (Wikipedia Foundation, Inc., 2009) From the investigations of the cultural heritage definitions, it was found that the cultural heritage significance can be assessed in different ways. It may deal with the individual site or be part of the regional or local overview. However, main issues of the cultural heritage assessment were separated into aesthetic value, historic value, scientific or research value including social value (Taboroff, 1994).

2.2.1 Types of the cultural heritage

It can be classified on the basis of physical or “tangible cultural heritage” and “Intangible cultural heritage”

1) Tangible cultural heritage

A description of tangible cultural heritage is buildings and historic places, monuments, artifacts, etc., that are considered worthy of preservation for the future. These include objects significant to the archaeology, architecture, science or technology of a specific culture

(Wikipedia Foundation,Inc., 2009). The Londoncharter adopts a wide definition of the term "cultural heritage" encompassing all domains of human activity that are concerned with the understanding and communication of the material and intellectual culture. Such domains include, but are not limited to museums, art galleries, heritage sites, interpretative centers, cultural heritage research institutes, arts and also humanities subjects within higher education institutions, the broader educational sector and tourism (Beacham et al., 2006).

2) Intangible cultural heritage

The intangible cultural heritage means the practices, representations, expressions, knowledge, skills - as well as the instruments, objects, artifacts and cultural spaces associated with the communities, groups and, in some cases, individuals recognize as part of their cultural heritage. This intangible cultural heritage, transmitted from generation to generation, is constantly recreated by communities and groups in response to their environment, their interaction with nature and their history, and provides the communities and groups with a sense of identity and continuity, thus promoting respect for cultural diversity and human creativity (UNESCO, 2009).

Both tangible and intangible cultural heritage are alike in that, they are very comprehensive term that includes three major entities, material culture (cultural properties), the geographic also human environment (ICOMOS, 1982). Thus, establish a symbiosis relationship between the tangible and the intangible. The intangible heritage should be regarded as the larger framework within which tangible heritage takes on shape and significance (ICOMOS, 2003).

Besides, it was reported that the cultural heritage can be divided into three groups based on the origin of materials composition that their genesis namely,

(1) Organic material : The materials are obtained from living organism either plants or animal, such as wood, leather, bone, amber, basketry.

(2) Inorganic material : These are produced from the raw materials obtained from the earth, such as metal, stone, glass, brick, clay, plaster.

(3) Composite material : These materials are contemporary art, such as mosaics, ethnographic artifacts, painting (GCI, 1999).

Also, the cultural heritage may be classified according to the selected types of cultural heritage sites that could be identified as in Table 2.1 (Modified from The World Bank, 1994).

Table 2.1 Selected types of cultural heritage sites (Modified from World Bank, 1994)

Main Categories	Sub - types	Comment
1. Sacred sites	1.1 Burial sites	• There are often discovered during the construction phase of projects.
	1.2 Sites of religious (spiritual significance)	• Important cultural sites were often inspired by religious beliefs and are still considered sacred places.
2. Archaeological sites (cont.)	2.1 Pre-historic sites	• The sites are often undetected or overlooked and frequently shed light on use or overuse of natural resources, changing survival strategies and social organization.
	2.2 Historical sites	• Many of the structures are still in use, may also point to changes in sea level, vegetation, hunting and agricultural practices.
	2.3 Engineering and industrial sites	• The introduction of new technologies metallurgy, mortars, arches - vaulting, industrial architecture which can be documented and understood by studying artifacts, earlier structures. • This in turn may suggest methods for conservation and may shed light on future avenues of technological advance.
	2.4 Submerged or marine sites	• New techniques of marine exploration have revealed many sunken ships and submerged sites of ancient human settlement.
	2.5 Sites within biologically diverse areas or protected reserves	• Management policies that protect both cultural and natural resources should be developed

Table 2.1 Selected types of the cultural heritage sites (Modified from World Bank, 1994) (Cont.)

Main Categories	**Sub - types**	**Comment**
3. Monumental sculpture	3.1 Cave sculpture	• The protection of these sites depends on an understanding of the processes of deterioration
	3.2 Architectural sculpture	• Exterior sculpture is often damaged by polluted air and rising water tables.
4. Monumental painting	4.1 Cave or wall painting	• Conserving wall painting, in the face of large tourist flows, requires careful planning.
	4.2 Monumental architecture	• Great works of architecture and urban planning demonstrate the introduction of new design principles and construction techniques.
	5.2 Historic settlements and town centers	• The protection of the historic core of cities depends on a comprehensive policy to address infrastructure and social needs.
	5.3 Cultural landscapes	• Landscapes, whether designed, organically evolved or relict, demonstrate mankind's responses to changing environmental conditions.
5. Architecture and town planning	5.1 Indigenous or Vernacular architecture	• Local materials, such as wood, mud brick ,stone, were used to build extra ordinary architectural compositions.
	5.2 Historic settlements and town centers	• The protection of the historic core of cities depends on a comprehensive policy to address infrastructure and social needs.

Table 2.1 Selected types of the cultural heritage sites (Modified from World Bank, 1994) (Cont.)

Main Categories	Sub - types	Comment
5.Architecture and town planning	5.3 Cultural landscapes	• Landscapes, whether designed, organically evolved or relict, demonstrate mankind's responses to changing environmental conditions.
6. Historic landscapes	6.1 Historic parks and gardens	• Returning gardens to their original appearance may require research into plant materials.
	6.2 Trade routes monuments and remains	• Remains of ancient trade routes, document early trade relations and cultural connections. Trading patterns, often long distance, are revealed in archaeological finds.

Unfortunately, most of the cultural heritage is irreplaceable or non - renewable resource (New Zealand Historic Places Trust, 2004). Depending on the materials and surrounding, many cultural heritages have been deteriorating causing by both abiotic factors and biotic factors shown in Figure 2.1.

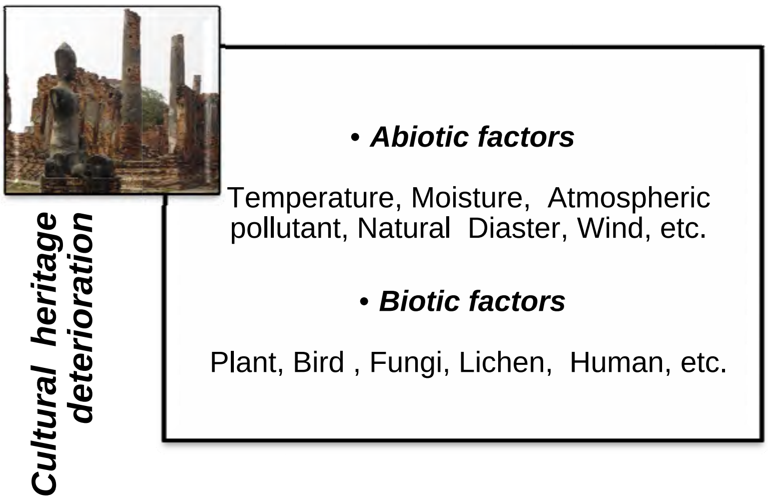


Figure 2.1 The factors causes the cultural heritage deterioration

Besides, basic causal factors of the heritage deterioration can be isolated from many research and can apply equally well to the behavior of either internal or external materials of the heritage. That basic causal factors were referred to as (Simpson, cited in Heaberlin, 2004).

(1) Environment (E) : Environment comprises a set of elements such as air temperature, rainfall rate, wind speed and amount of pollutants which can be well defined. The environmental factor has special significance to the widest range of effects on external materials and design elements.

(2) Use (U) : Deterioration by use depends on the behavior and habits of the occupants which are generally reflected in the function of a building or part of a building.

(3) Design (D) : This factor includes a number of causal elements which are beyond numerical interpretation that should be aware of the performance of design details and elements specified, and

of the materials out of which they are made. The design factor excludes intrinsic material properties but includes the manner in which they are assembled.

(4) Workmanship (W) : Workmanship refers to the causal elements which cover the total effort of the builder in erecting a building. Standards of workmanship vary within a set of defined tolerances or within limits implicit to the job at hand. Poor workmanship can result in the deterioration of a building by means of faulty materials and workmanship in the sense of craft.

Elaborating on the identification of four causal factors of weathering on a material with the intrinsic properties (P), provides a symbolic understanding of total deterioration. It was expressed by following equation.

$$\textbf{Total Deterioration} = f\{(E), (U), (D), (W)\}\{(P)\} \quad \text{----} \quad 2.1$$

In addition, the deterioration problems also related to long - period exposure. Heritage material has a critical limit for the service life so longe-period exposed leading to more severe deterioration (Figure 2.2) (Mattsson and Oftedal, n.d.).

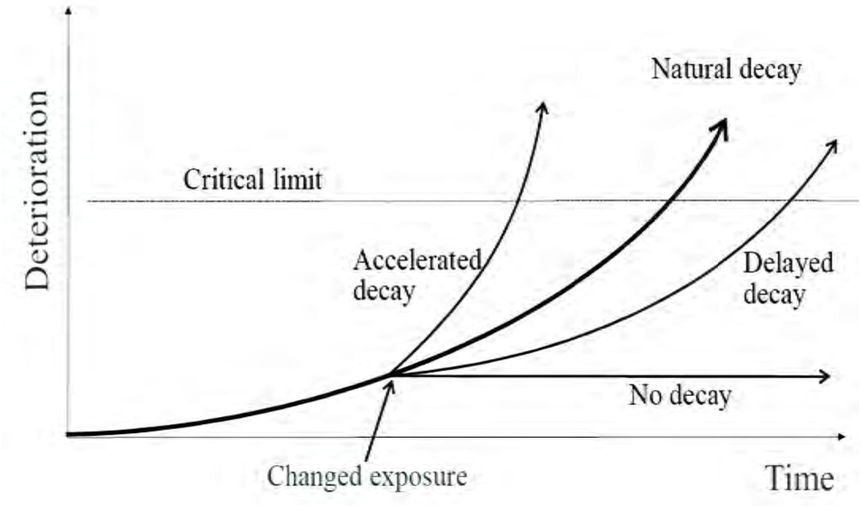


Figure 2.2 Service life for building materials depending on change of exposure (Mattsson and Oftedal, n.d.)

Also furthermore, deteriorated factors were identified as the risk endangered to the cultural heritage. It was studied and revealed the specific example of the risk types and the relative importance of implementing means for control, might supplied by Table 2.2.

Table 2.2 The specific example of types of risk and the relative importance of implementing means for control (Waller, 1995)

Agent of Deterioration	***Type of Risks***	**Example of Risks**	**Levels for Control**							
			location	***site***	***building***	***room***	***cabinet***	***specimen***	***policy***	***procedure***
Physical Forces	1	Earthquake								
	2	Mishandling								
	3	Poor support								
Water	1	Flood								
	2	Roof leaks								
	3	Rising damp								
Pests	2	Infestation								
Pollutants	1	Nearby disaster								
	2	Corrosive cleaner								
	3	Storage materials								
Light, radiation	3	Light exposure								
Incorrect temperature	2	Thermal shock								
	3	Higher than ideal								
Indirect Relative humidity	2	HVAC malfunction								
	3	Higher - lower than ideal								

Type of risk : 1 = catastrophic, 2 = severe, 3 = mild/gradual

Most important ☐ ☐ ☐ ☐ Least important

2.2 Abiotic factors

2.2.1 Temperature

The temperature is primarily factor for cultural heritage conservation. The presence of imbalancing temperature, lead to the potential risk to the heritage, which depending on the factors, such as heating, air conditioning, ventilating system (HVAC) and the building structures (Camuffo et al., 2001).

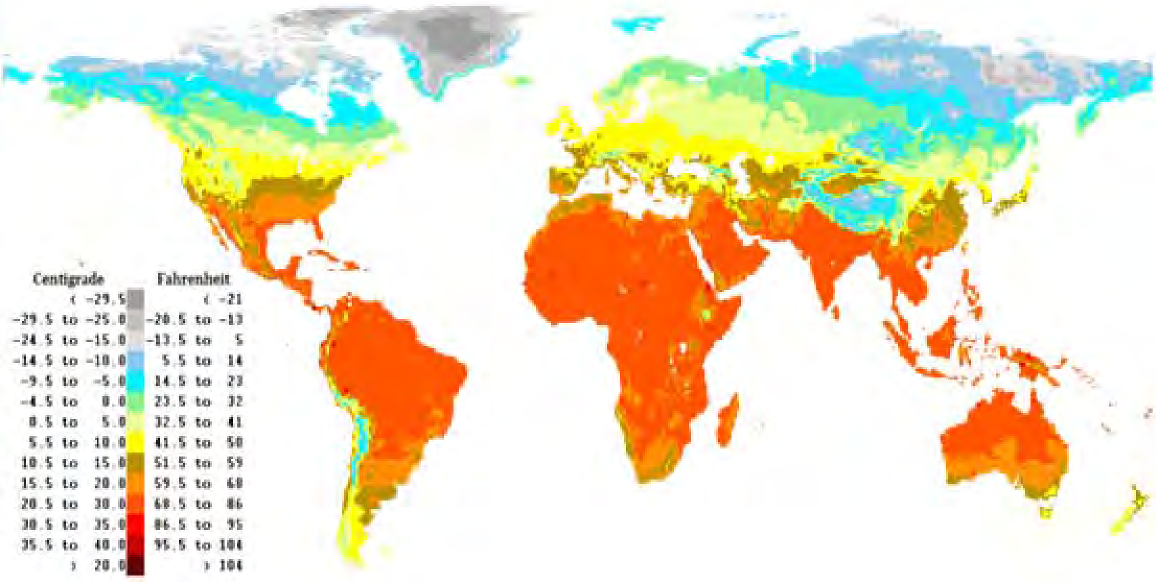


Figure 2.3 Annual average temperature (United Nation, Food and agriculture Organization, 1999)

Global temperature has risen by about 0.6°C over the last 100 years (UCL, 2005) Moreover, the global mean temperatures are expected to rise by 1.4 to 5.8° C by 2100 (Figure 2.3) (UNESCO, World Heritage Centre, 2006).

Rising temperature was also observed to be risk for deterioration of materials and contents, since it would increase the rate of chemical reaction and biochemical deterioration (Adams, 2007). The fluctuations of temperature also cause the weathering processes of inorganic materials exposed to wet - dry and cold - hot cycles that the mere presence of resistant structures in the cracks represents an additional factor for further widening of inter - crystal spaces and cracks (Dornieden et al., 2000).

2.2.2 Humidity and Rising damp

Correspondingly, study was carried out to estimate the optimum of relative humidity for material heritage and describes as in Table 2.3 (Royal Cornwall Museum, 2008). Anyway some case was implied the ideal relative humidity for all museum objects should be from 45 - 55% (Malla, 2006).

Table 2.3 The optimum of relative humidity for material heritage

Material		Optimum relative humidity range (%)
Metal work	Non-ferrous	50 % when sorted/displayed with other materials
		35 % dedicated metal display/storage
		< 35 % where a microclimate is necessary
	Ferrous	50% when stored/displayed with other
		35% dedicated metal display/storage
		< 15% where a microclimate is necessary
Organic materials		50% when stored/ displayed with other microclimates should only be provided after taking advice from a conservator
Waterlogged, Wet stored materials		100% provided by a microclimate
Inorganic materials		50 % when sorted/ displayed with other materials

Actually, it was so difficult to control the moisture because of many sources of the moisture attacked to heritage. Mainly sources of the moisture were derived from wet precipitation and ground water, indicated there are,

- Fog
- Dew
- Rain
- Ground water

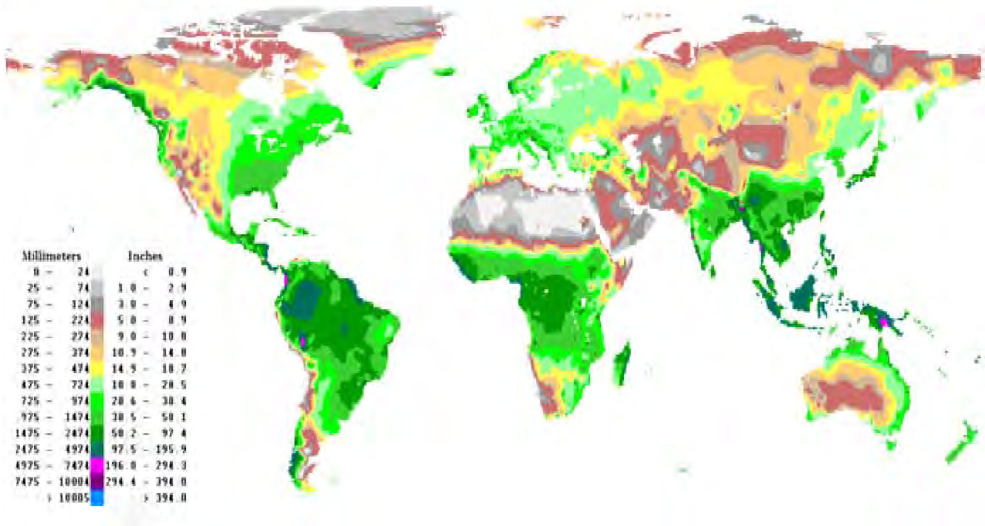


Figure 2.4 Annual average rainfall (United Nation, 1999)

Dramatically changing of the atmospheric moisture, have been causing the threatens cultural heritage in a multitude of ways. There are three major categories of exhibit' deterioration affected by the relative humidity (RH) of the environment (Pavlogeorgatos, 2003).

- Changes in size and the shape of the exhibits
- Changes in the rate of the deterioration chemical reactions
- Changes in biological deterioration source

Humidity causes major damage to historic building, have revealed that humidity often appeared near the base of the building and led the surface materials to crack, peel and stains could be evident (United Nations Economic Commission for Europe, n.d. ; Museum Climate Control, Stefan Michalski 1994). However, additional impacts which result in more damage are derived from damp and salt attack (Spennemann, 2008).

2.2.3 Rising damp, Falling damp and Salt attack

The country which have hotter, drier climates and more saline soils leading to greater rates of 'transpiration' through the walls and to the accumulation of soluble salts at the evaporation zone (Young, n.d.) The result is related with following problems,

- Rising damp, Falling damp
- Salt attack

Rising damp, a world-wide phenomenon, is a major cause of decay to materials such as stone, brick and mortar which contain porous. When the pores are connected, air or water can pass through them, the material is said to be permeable. Rising damp occurs as result of capillary action (suction) of water from the ground through the network of small pores in a permeable masonry material, capillary suction.

Unlike rising damp which is most commonly evident at ground level, falling damp occurs towards the top, or in the middle of a wall. These causes of falling damp vary. However, it can usually be attributed to a failing in the structure of the wall (Adelaide city council, n.d.) (Figure 2.5).

a. b.

Figure 2.5 The characteristic of rising damp and falling damp : a. rising damp and b. falling damp (Heritage Victoria, 2008)

Both rising damp and/or falling damp are associated high concentrations of salts, generally derived from many sources, may be one or a combination of the following (State Heritage Branch, 1997).

- Saline soils and groundwater
- Sea-spray
- Air-borne (meteoric) salts, Air pollutants
- Biological - pigeon poop, micro-organisms, leaking sewers
- Salt naturally occurring in the stone, brick clay or mortar sand
- Salt water used for puddling brick clay or mixing mortar
- Salts used for de-icing roads in cold climates
- Inappropriate cleaning compounds

Obviously, These salts consist of a combination of positively and negatively charged ions known as cations and anions. Table 2.4 showed ions that make up the salts commonly encountered in materials (Heritage Council of NSW, 2004).

Table 2.4 Cations and Anions of commonly salts encountered in materials

Cations	**Anions**
Sodium (Na^{+})	Chloride (Cl^{-})
Potassium (K^{+})	Sulphate (SO_4^{2-})
Magnesium (Mg^{2+})	Nitrate (NO_3^{2-})
Calcium (Ca^{2+})	Carbonate (CO_3^{2-})

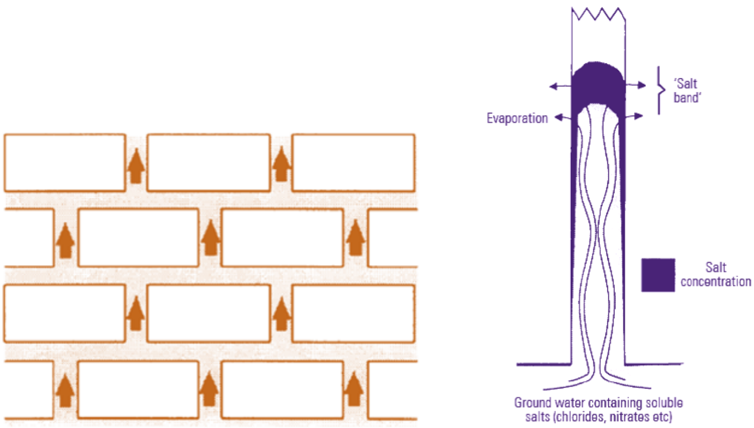
Salt content is consisted of distinct soluble salts mainly, sodium chloride (NaCl), potassium chloride (KCl), sodium sulfate (Na_2SO_4), potassium sulfate (K_2SO_4), sodium nitrate ($NaNO_3$), potassium nitrate (KNO_3), sodium carbonate (Na_2CO_3), potassium carbonate (K_2CO_3) and calcium sulfate ($CaSO_4.2H_2O$) (Gonçalves et al., 2006 ; Louren et al., 2005).

Not only soluble salt which were influenced to the salt attack but salt attack also related with the other factors that described by the salt attack equation as follows (Figure 2.6)

Figure 2.6 Salt attack equation (Modified from State Heritage Branch, 1997)

These mentioned occurrence causes substantial damage. Owing to the result, salt attack causes salt weathering which has been considered as one of the major building defects and can be a significant hazard to the cultural heritage (Cardell et al., 2003).

Because of high salt concentrations often cause extensive fretting and crumbling of the lower parts of material (Ahmad and Rahman, 2007). These deterioration were explained by the mechanisms proposed that concerned with the thermodynamic and kinetic factors influencing crystallization pressure, hydration - osmotic pressure, mineral dissolution and thermal expansion (Scherer, 2004 ; Rodríguez - Navarro and Doehne, 1999)



a. b.

Figure 2.7 The mechanism of salt attack : a. water rising through porous material and b. salt attack mechanism from rising damp (Safeguard Europe Ltd., 2007)

Under surrounding conditions, the water evaporates and the salt is deposited on the surface or within the pores, or in both positions of the materials. If the salty growth of florescence appearing on a surface, it is known as " Efflorescence effect ". Crystallization that occurs invisibly within the pores is called, "Cryptoflorescence effect". It is not unusual for both forms of florescence to occur together (TÜmer, 2003).

All of the salts growth commonly encountered, sodium sulfate (Na_2SO_4) is known to be the worst. Two main mechanisms are proposed to explain the extensive damage which caused by sodium sulfate; hydration pressure and crystallization pressure. Hydration results in large volume expansion, about 314 % as the anhydrous phase of sodium sulfate (thenardite) converts to its decahydrate phase or mirabilite (Tsui et al., 2003). It causes the mechanical stress by the crystallization pressure (Espinosa et al., 2007).

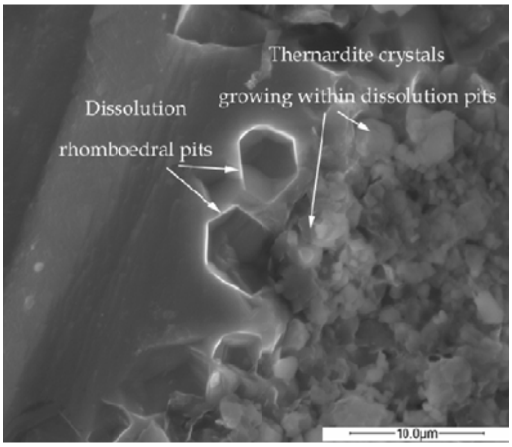


Figure 2.8 Scanning electron microscopy photomicrograph of calcite grains showing etch pits filled with Na_2SO_4 crystals (Ruiz - Agudo et al., 2007)

Not only the rate of salt attack decay depends on type of salts, but also a period of exposure - time (Figure 2.9).

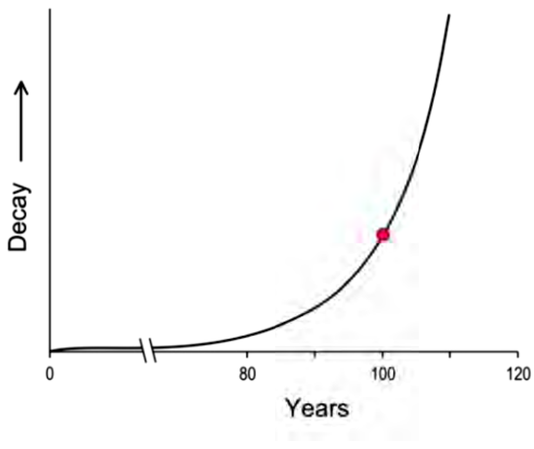


Figure 2.9 Rate of salt attack decay (Young, n.d.)

In addition, it was revealed that the salt weathering can induce the deterioration of architectural heritage which is considered to be accelerated drastically in marine environments (Cardell et al., 2003). Further, some study was suggested that the salt weathering chances are affected by the melting of coastal sea ice increasingly (Zezza, 2006).

2.2.4 Light / Illumination

The Illumination source both from artificial and natural sources as well as visible - invisible light are the factors effecting on heritage. In spite of, it is known that, Ideal ultraviolet radiation for organic material in museum is 75% MW/Lumen (Malla, 2006) but is hardly to control appropriately. Therefore, the deterioration process of materials which requires energy would initiate under improper control of ultraviolet. The deterioration reaction is interacted by two processes. There are photochemical action and radiant heating effect (Cuttle and Iesna, 1996) that had been summarized the light impacts on the heritage as following (Pavlogeorgatos, 2003).

- Accelerate the deterioration and corruption of several materials, because it acts as a catalyst to their oxidation
- Subsidize and raise the fragility level of cellulose fibers
- Corrode significantly every natural fabric
- Deteriorate exhibits in Natural History Museum
- Increase the surface temperature of exhibits

- Color will fade in the presence of light, especially drastic in natural organic materials (Heritage Conservation Centre, 2001).

However, although free from direct sunlight it was reported that stable light as the hemisphere also potentially harmful because of its spectral characterized by a content energetic radiations, UV and short visible wavelengths (Ezrati, 2008). Furthermore, the presence of light alone is less of a detrimental factor compared to when it combined with other factors such as the presence of O_2 and moisture which can generate chemical reactions leading to the breakdown of materials (Heritage Conservation Centre, 2001).

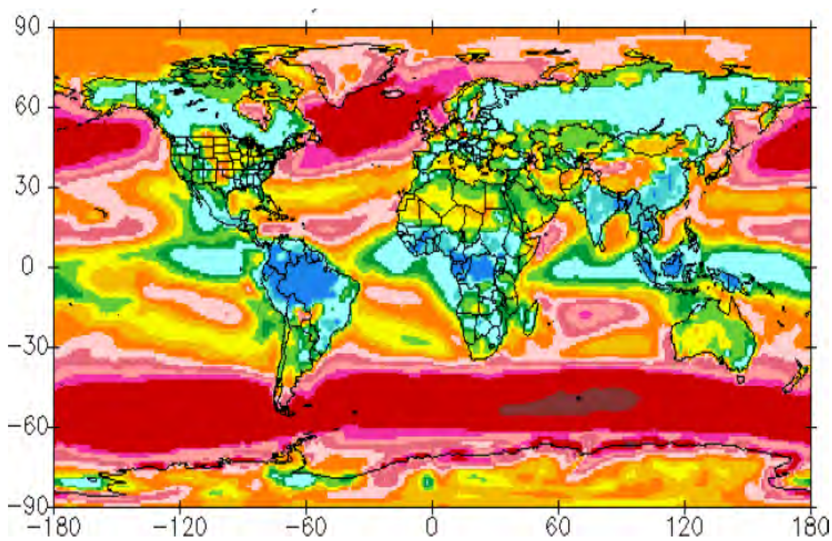
Some study was carried out and reported. The display lighting which enhances object appearance may be legitimate for many museum exhibits but is generally inappropriate for works of art, leading to conflict with recommened illuminance maxima, particularly the 50 lux level for more sensitive objects. To improved basis for specifying control, it should permit more flexible approach to reconciling competing requirements for the exhibition and conservation and also be related to actual conditions of exhibition museum and art galleries (Cuttle, 1988).

2.2.5 Wind

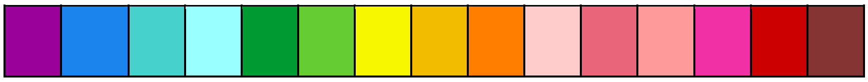
Wind has caused structural damage particularly in tropical and sub - tropical climates which had observed and revealed that had been changing weather patterns including the increased frequency and intensity of storms, phenomena. These may have an accelerated impact on the sites (Figure 2.10, 2.11) (ICOMOS, 2007).

Many researches were conducted and concluded the deterioration of historical sites by wind as follows,

- Wind driven rain causing penetrative moisture into porous cultural heritage materials.
- Wind transported salt causing the static and dynamic loading of historic or archeological structures.
- Wind picks up abrasive particles as, sand and pebbles that cause corrosion or erosion of surface and structural collapse (Hughes and Lazer, 2000 ; Harrowfield, 2006).
- Wind transport air pollution (TÜmer, 2003).
- Wind may vigorous damage to heritage, as Figure 2.12



Metres / sec. : 0.0 1.3 2.7 3.5 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5 9.0 > 12.0



Miles / hrs. : 0.0 2.9 6.0 7.8 10.0 11.2 12.3 13.4 14.5 15.7 16.8 17.9 19.0 20.1 >26.8

(The original scale units are metres / sec., the conversion to miles / hrs. is approximate.)

Figure 2.10 Annual average wind speed measured 50 metres above the ground or sea, July 1983 – June 1993 (NASA, 2004)

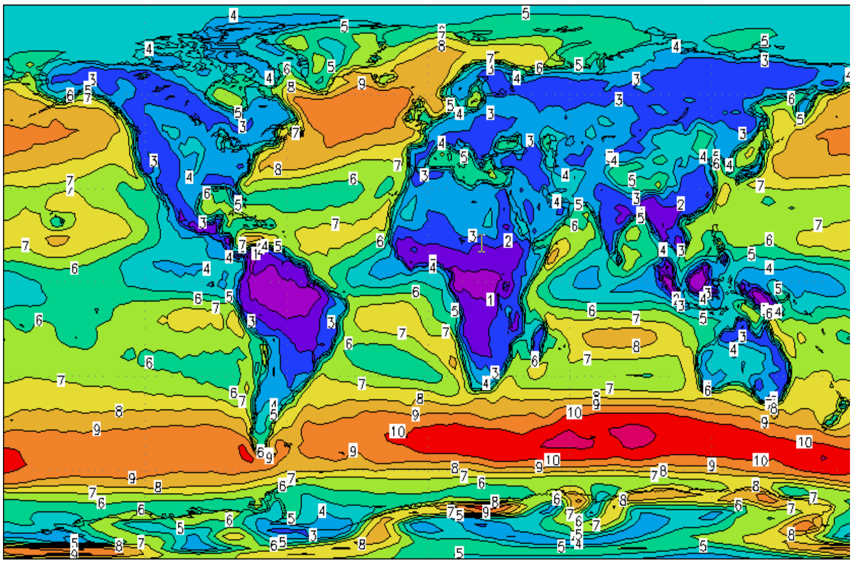


Figure 2.11 Mean wind speed in ms^{-1} measured 10 metres at ground level. for the period 1976 - 95 (The World of Wind Atlases, 2008)

a. b.

Figure 2.12 The indirect impact from wind to cultural heritage, Kent, England : a. Stonewall Park and b. Chiham Castle (English Heritage, 2006)

2.2.6 Atmospheric pollutant

Atmospheric pollution may be called as " The blackening effect " (Brimblecombe and Grossi, 2006). It has a significant influence on the weathering (Grieken et al., 1998) and probably the most important threat for the heritage preservation (Pavlogeorgatoe, 2003).

Both indoor and outdoor emission factors such as sulfur oxide (SO_x) carbon oxide (CO_x) nitrogen oxide (NO_x) and aromatic compounds can cause chemical damage or soiling onto heritage surfaces by deposition of particulate materiasl or absorption of present gases. Although scouring or loss of particles appeared to be much smaller in an indoor environment than outdoors, indoor and outdoor particulate accumulation were similarly patterns, it was followed the exponential relationship (Adam et al., 2002) and also it was found that, the internal distribution with respect to seasons (Ford and Adams, 1999) and severe weathering due to the heavily polluted urban atmosphere from the nearby traffic (Moropoulou et al., 2002).

Suspended particulates, especially fume, can smooth and eventually, corrupt details of museum exhibits, increase the possibility of the development of microorganisms, leave traces of aesthetic and chemical pollution on the surface of exhibits and give a sense of neglectfulness. Besides, ozone is a powerful oxidizing agent in almost every object that could be housed in a museum. It also increases the oxidation of iron and silver and the sulfurization of silver and copper. Finally, it breaks any double bond in carbon chain in contact, thus causing the creation of vertical cracks on materials (Pavlogeorgatos, 2003).

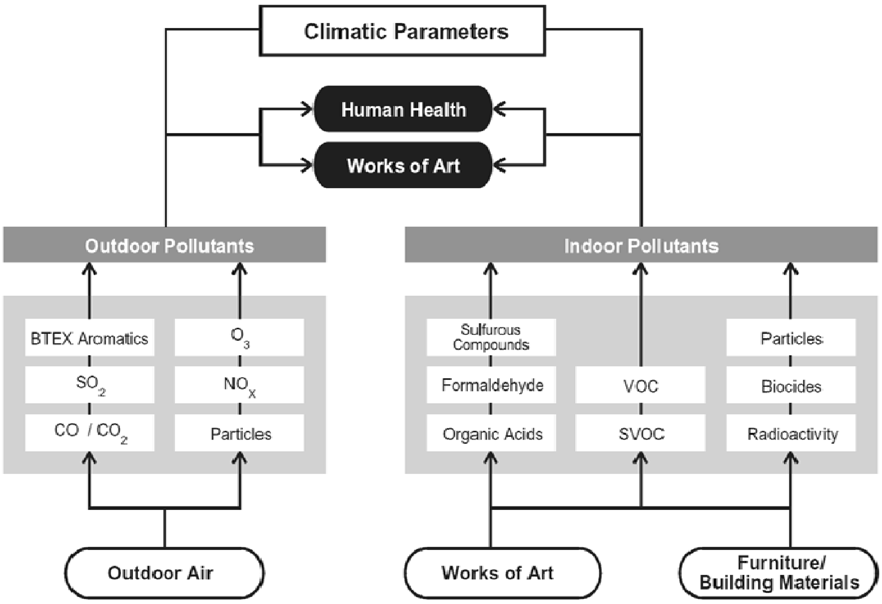


Figure 2.13 Outdoor and indoor emission sources affecting human and works of art in cultural institutions (Schieweck et al., 2005)

Volatile organic compounds (VOCs) such as formaldehyde and organic acids which were investigated within the heritage buildings. Most of the VOCs detected in the ambient air are associated with packaging and building products used for furnishing magazines and building exhibition cases. Furthermore,they are associated with products used for preservation and restoration. Wooden shelves and drawers were identified as sources of terpenes and other VOCs. Compounds such as lindane and 1,4-dichlorobenzene are still used as preservatives against insects and fungi (Schieweck et al., 2005), even through, there were not clearly proved, they are effecting heritage material, but they were known effecting on health of human.

Air pollution is also the most serious causes of degradation in carbonate stone, which in the form of marble, limestone and similar materials comprised some of the most important monuments and artifacts in the world (Clarelli et al., 2007). Actually, sandstone, limestone, marble are particularly sensible to the reacts of sulfur dioxide they react forming gypsum (calcium sulfate) especially, sulphation is found to be the main damage mechanism occurring on the cement mortar (Tittarelli et al., 2008). These reaction was presented as following equation (Natalini et al., 2005).

$$CaCO_3 + SO_2 + (1/2)\,O_2 + 2H_2O \longrightarrow CaSO_4 \cdot 2H_2O + CO_2 \quad \text{--- 2.2}$$

Slow chemical procedure has rotten the bonds between the calcite grains of the material and produced an irreversible modification of the material chemical structure (Natalini et al., 2005). Mechanism of interaction not only the surface but also the boundaries of the grains, the crystal planes and the intermolecular spaces or porous at the microstructural level which relate to the strength. Figure 2.14 shows the deterioration of the statue after chemical aggression (Denkmalpfledge, cited in Victorian Association for Environmental Education, 2005).

a. b.

Figure 2.14 The damage to a German sandstone statue created in 1702: a. In the 1908 and b. In the 1969 (Westfaliches Amt fur Denkmalpfledge cited in Winkler, 1987)

The effect of other pollutants such as ozone, carbon dioxide and hydrogen sulfide, etc. could be significant in natural aging conditions (Bacci et al., 2000).

2.2.7 Acid rain

"Acid rain" is a broad term referring to a mixture of wet and dry deposition (deposited material) from the atmosphere containing higher than normal amounts of nitric acids (HNO_3) and sulfuric acids (H_2SO_4). The precursors, or chemical forerunners of acid rain formation result from both natural sources such as volcanoes, decaying vegetation and man-made sources. Primarily emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) are resulting from fossil fuel combustion. Acid rain occurs when these gases react in the atmosphere with water, oxygen and other chemicals to form various acidic compounds. The result is a mild solution of sulfuric acid and nitric acid. When sulfur dioxide and nitrogen oxides are released from power plants and other sources, prevailing winds blow these compounds across state and national borders, sometimes over hundreds of miles (Environmental Protection Agency, 2007).

Acid rain is a tremendous damage to inorganic materials such as stone and metals. Some of the greatest measurable effects of acid rain can be observed on human constructions, particularly old buildings with facades built of porous stone such as limestone and corrosion - prone metals such as copper (Mink, 2009) bronze, paint and stone. These effects significantly reduce the societal value of buildings, bridges, cultural objects (Figure 2.15) (Environmental Protection Agency, 2007).

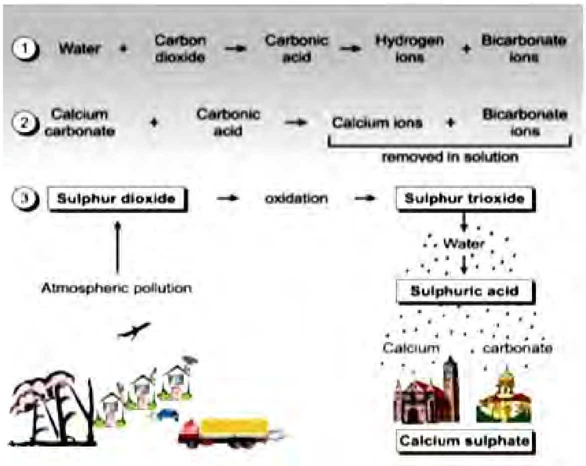


Figure 2.15 The cycle of acid rain and its effects on weathering processes (Elgohary, 2008)

In recent decades, it was reported that acid deposition and the role of acidic air pollutants has become the cause of considerable concern at both national and international levels. This concern has centered mainly around adverse environment , health effects and on damage to historical monuments (Bravo et al., 2006). Figure 2.16 was shown the areas of the world presently and potentially affected by the acid rain (HRW., n.d.) and Figure 2.17 was presented the five sites that have been exposing to the high risk from the hazards associated with acid rain (Mink, 2009).

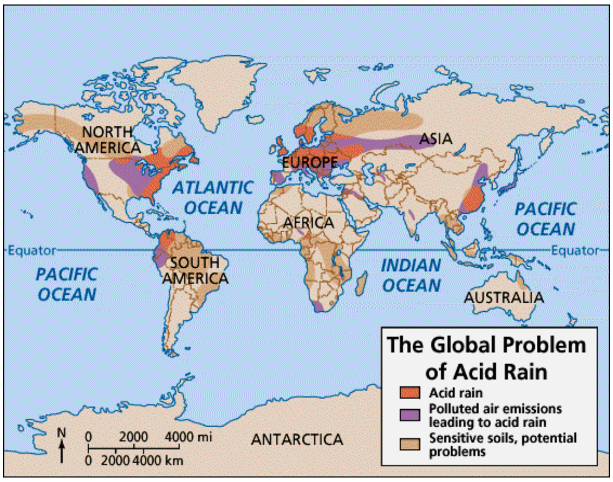


Figure 2.16 The Global Problem of Acid Rain (HRW., n.d.)

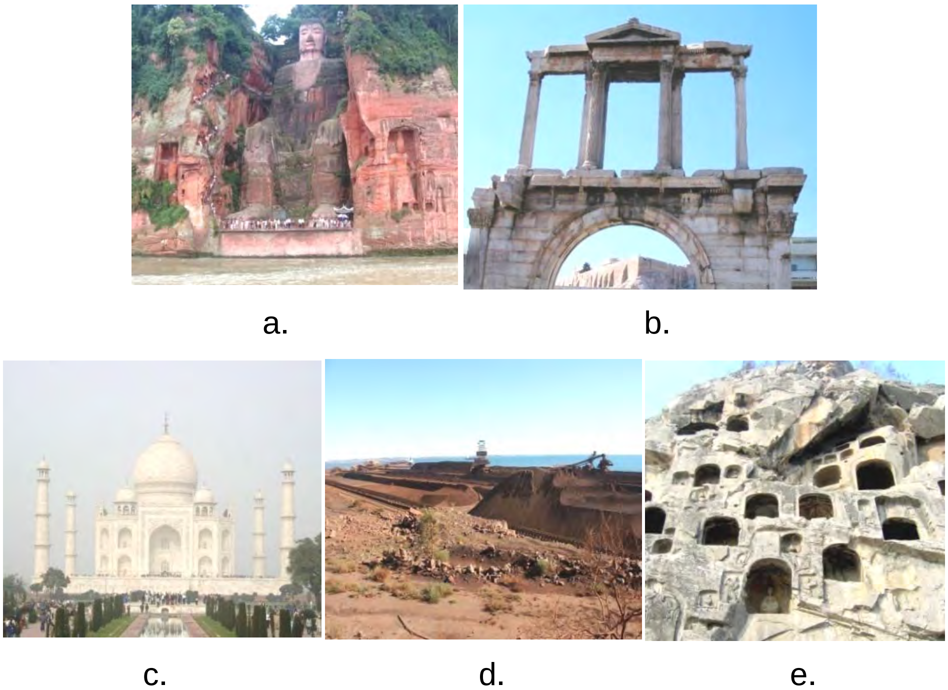


Figure 2.17 The five of high risk sites associated with acid rain (Mink, 2009) : a. Leshan Giant Buddha, Mount Emei (China, Buddhist) b. Acropolis of Athens (Greece, Ancient Greek) c. Taj Mahal (India, Mughal Islam) d. Dampier Rock Art Complex (Australia, Australian Aboriginal) and e. Longmen Grottoes (China, Buddhist)

2.2.8 Natural disaster

Things appear to be getting worse in two ways, natural disasters appear to be becoming more frequent and their effects more severe (UNEP, 2000) The number of disasters has increased more than four fold since the 1960's from an average 44 disasters each year in the 1960's to an average 181 disasters each year in the 1990's (EM-DAT, 2007). The number of natural disaster and cumulative numbers of natural disasters were reported as in Figure 2.18 and Figure 2.19. It shows definite tendency to non - linear increase. Because of this tendency leads to the conclusion that related with the impacts. Not only impacts to human, but also there are usually severe, immediate and often irreparable to cultural heritage.

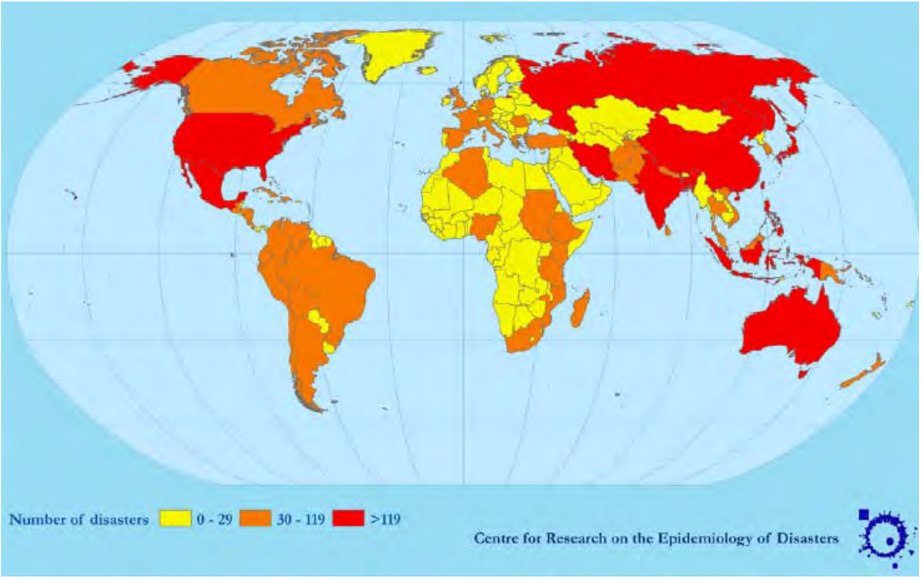


Figure 2.18 Number of natural disasters by country; 1976-2005 (CRED, 2008)

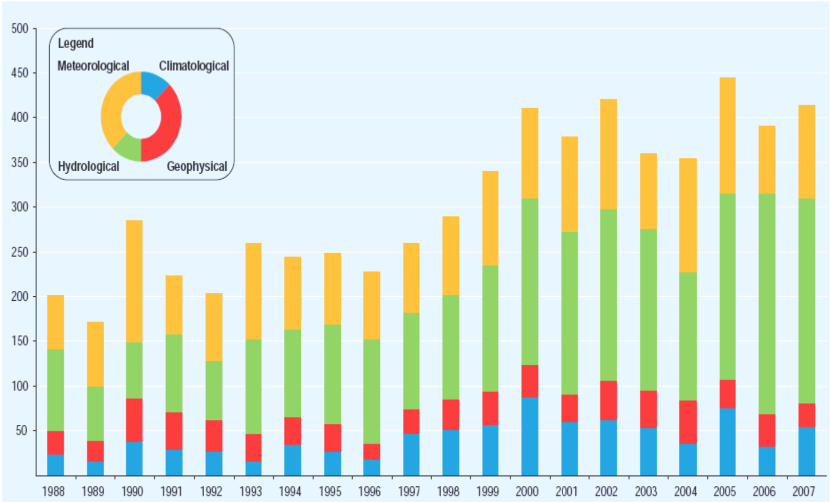


Figure 2.19 Natural disaster by major disaster groups : 20 years trend (CRED, 2008)

Cultural heritages are particularly vulnerable to the effects of natural disasters as they are non-renewable global resource. Natural disasters are affecting on cultural heritage in different ways. The main types of natural hazard that affecting cultural assets are follows,

- Fire
- Lightening ground strike
- Flooding
- Earthquakes
- Tsunami
- Wind, Storm
- Storm surge (UCL, 2005)
- Sea level rise and Coastal change (Taboroff, n.d.)

However, people generally think of disasters as events that occur suddenly but some disasters occur so slowly (Look and Spennemann, 2001). Therefore, what was learned from the past can be transferred to plan and prevent for many cultural resources.

2.3 Biotic factors

Biotransformation processes has a worldwide diffusion and attains highest levels in warm humid - climates where the environmental conditions are extreamly favourable to the growth of most organism (Tiano, 2001). Especially tropical and subtropical climatic regions cultural properties, it has received severe attacks of various organisms and many of them have been lost. Tropical countries suffer through biodeterioration more than the countries of temperate climates because of the hot and humid environment prevailing in the tropics (Agrawal, 1995).

Biological deterioration can be found in the full range of these materials also causing stains which were noted that, the most of the stains were damaging (Flores - Colen et al., 2008). The classification of important organism group that causing the biodeterioration process are following,

- Fungi
- Bacteria, Archaea
- Lichen
- Algae
- Plant, Weed
- Animal (Insect, Bird)
- Human

There are related to deterioration of cultural properties. The major types of deterioration derived from metabolic activity of mentioned organisms are also related with kind of heritage material, status of their conservation and environmental conditions.

2.3.1 Fungi

Fungi are chemoheterotrophic organisms that were found on both organic and inorganic materials. The growth of fungi is known as severe impact on the heritage. Generally, fungi deterioration is quite common in the rainy season when relative humidity go up to 80 - 95% and the rate of fungal development is enhanced by warmth 25 - 40°c in suitable pH range (Chiraporn Aranyanak, 1995).

Mostly, fungi feed on organic, but some of all investigation reported that the waste products of algae, bacteria or decaying leaves and bird droppings could provide such food (Sharma et al., 1985) and that diversity decreased gradually and dominance of particular species increased with the time factor (Jain et al., 2008).

Epistemic fungi belong to the most stress resistant eukaryotic organisms because of their high temperature tolerance, their resistance against ultraviolet radiation and their ability to survive long periods of complete desiccation of vegetative cells. They are the most successful conquerors of bare rock surfaces in arid and semi - arid environment (Sert et al., n.d.). Their behavior like as “Sleeping beauty” (Dornieden et al., 2000).

Regularly, microbial induced decay processes, drastic changes in appearance, color, structure (Gorbushina and Petersen, 2000) Microbial activity can have an important impact on the durability of building material such as concrete, mortars, composites timber and gypsum

(Gaylarde et al., 2003). The ability of fungi could interacted with minerals, metals, metalloids or organic compounds through biomechanical and biochemical processes which make them ideally suited as biological weathering agents of rock and building stone (Burford et al., 2003) and accelerate the breakdown of rocks through the growth of fungal hyphen (Arocena et al., 2003). Also, it was revealed that fungal mycelium as a source of nutrition for arthropods is accompanied by the transportation of fungal spores in animal intestinal tracts (Gorbushina and Petersen, 2000).

Furthermore, it has hypothesized that black color occurrence on mables of historic buildings could have a biogenic origin and that related to microbial melanin (Saiz-Jimenez, 1995). Some cases was found an orange - brown film formed on mable by *Sporotrichum* genus and it comprised of 66% oxalate, 16% calcite, a significant amount of phosphate and low amount of nitrates (Monte, 2003).

Eventually, from fungal species that were widely investigated. It was recognized the dominant species which were encountered on heritage material are presented following,

- Wood : *Geomyces, Hormonema, Cladosporium, Penicilium, Cadophora* (Held et al., 2005).
- Stone ; *Coniosporium, Capnobotryella, Rhinocladiella, Massarina, Cladosporium, Sarcinomyces, Phaeococcomyces, Mycocalicium, Lophiostoma, Monodyctis, Phoma* (Sert et al., n.d.) *Aspergillus sydowi, Aspergillus flavipes, Fusarium moniliforme, Fusarium oxysporum, Cephalosporium acremonium, Papulospora* sp. (Jain et al., 2008).

- Lime mortar, Lime plaster, Frescoes : *Acremonium charticola, A. strictum, A. kiliense, Acremonium* sp*., Aspergillus sydowii, Aureobasidium pullulans, Beauveria* sp*., Cladosporium* sp*., Cladosporium sphaerospermum, Chrysosporium* sp*., Engyodontium album, Mycelia sterilia* (dark pigmented), *Scopulariopsis brevicaulus, Verticillium lecanii, Verticillium suchlasporium, Verticillium* sp*.* (Gorbushina and Petersen, 2000) *Aspergillus versicolor* (Vuill) (Sampŏ and Mosca, 1989) *Penicillium crysogenum* (Milanesi et al., 2005) *Fusarium* (Gorbushina et al., 2003).

2.3.2 Bacteria / Archaea (blue green algae)

Biological colonization, mainly cyanobacteria as deteriogens on materials (Crispim, 2005). Because it can establish the disaggregation of the materials because of rhizoid penetration (Migue, 1995). Such biological activity promotes detachment of particles by rain and accelerates weathering leading to pit formation (Danin and Caneva, 1990). Several species of bacteria have been detected from the heritage can be devided into 2 main nutritional groups, chemiolithoautotrophes and chemioorganotrophes

(1) Chemiolithoautrophes the metabolic of these species can give out the strong inorganic acid, sulfuric acid and nitric acid respectively. Initially the attention was focused upon the sulfur - oxidizing bacteria, *Thiobacillus sp. (*Tiano et al., 1975).

Besides, The physiology groups such as, thechemolithotrophic, thionic, nitrifying bacteria, chemoorganotrophic *Streptomyces* in the brick and mortar masonry samples were revealed using selective cultivation. In the limestone microbial community the bacteria of *Bacillus* genera and the fungy *Aspergillus* sp., *Penicillium* sp., *Alternaria* sp., *Cladosporium* sp., *Tritirachium* sp. were predominant. The green biofilm was formed by microalga *Chlorella*. The methylotrophic bacteria, *Bacillus mycoides, Rhodococcus erythropolis, Aminobacter aminovorans, Pseudomonas reactansu Flavobacterium frigoris* were isolated from the brick and the limestone samples (Petushkova et al., 2007).

(2) Chemioorganotrophes It have been investigated and were revealed that several organic acids can solubilize the minerals components of stones (Henderson and Duff, 1963). Among the wide range of heterotrophes isolated, most could be assigned to the genera, *Flavobacterius* and *Pseudomonas* (Lewis et al., 1987).

2.3.3 Lichen

Lichen are symbiotic organisms between algae (photobiont) and fungi (mycobiont). Among the agents of biodeterioration of stone artifacts, lichens play an important role owing to their capacity to grow on a variety of substrates under different environment conditions (Monte, 1993).

Based on their morphological appearance, it could be categorized lichen into three groups, namely crustaceous, foliaceous and fructicose types. They mostly grew in dry conditions that received direct solar radiation.

All of the lichen types, crustaceous lichens are closely attached to the substratum and more significant in stone weathering than foliose and fruticose lichens. It was considered and found that it was very dangerous to the stone as it had a destructive effect through biochemical action and stain the stone. The effect was increased by chemical reaction as the secretion of oxalic acid (Sadirin, 1995) which can effectively dissolve minerals and chelate metallic cations (Chen et al., 2000).

For the other species, it was revealed that each species of lichen caused a different amount of damage (Seaward, 1988) depending both upon the acid metabolites exuded as well as the depth to which the thallus has penetrated the stone structure (Monte and Nichi, 1995).

These metabolic substances caused compositional change in the stone surface layer immediately beneath the lichen structure, with depletion of its main chemical elements such as a aluminium, magnesium, manganese, zinc, silicon, calcium, potassium, ferous and the accumulation of some of these, especially Calcium inside the thallus (Nimis, cite in Monte, 1993). Also, it was reported that some of which change color based on adsorbed metal content (Easton, 1994).

Not only chemical damage but lichen can also cause physical damage (Mohammadi and Krumbein, 2008) depending upon the acid metabolites excluded as well as the depth to which the thallus has penetrated the structure (Monte and Nichi, 1995). Each species causes a different amount of damage (Seaward,1988) from the penetration of their hyphae which cover and deep into the historical heritage. This leads to destabilize stone texture (Fig 2.20, 2.21).

Anyway, some cases was indicated, the lichenic coat reduces the presence of water inside the rock, thus protecting the rock material from physical decay and disintegration (Garcia-Vallès et al, 2003).

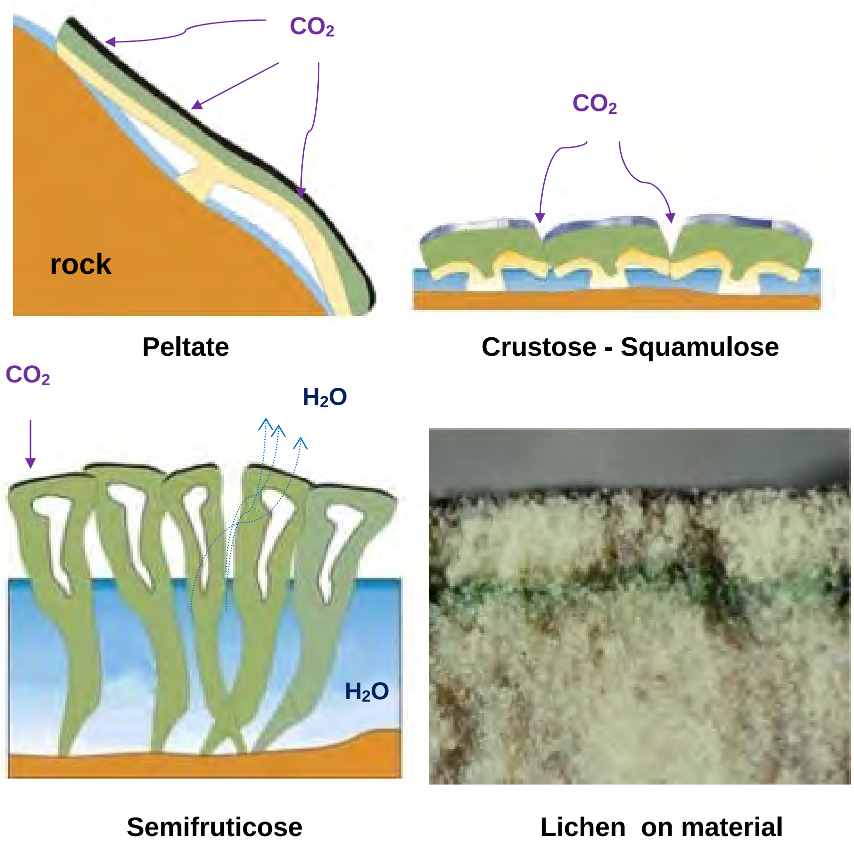


Figure 2.20 Diagram of lichen on material (Modified from BÜdel and Weber, 2005)

Figure 2.21 Lichen Growth on Giant Buddha of Srichum Temple in Sukhothai historic site, Thailand (The Fine Arts department, 1999)

2.3.4 Algae

Algae can develop wherever a suitable environment. The growth of algae is promoted by high degree of atmospheric humidity. These microorganisms are very sensitive to moisture content as they develop and reproduce in a water film on the stone's surface (Tiano, 2001). During dry and cold weather, these organisms will die and leave a dirt deposit of dead cells and reproductive bodies which permit rapid new growth as soon as suitable weather returns.

The occurrence of algae on monuments or plaster had been investigated and discovered that the most representative genera were found on heritage such as *Anabaena* sp., *Nostoc* sp. *Borzia* sp., *Lyngbya* sp., *Chroococcus* sp., *Oscillatoria* sp., *Phormidium* sp., *Plectonema* sp., *Scytonema* sp., *Myxosarcina* sp., *Synechocystis* sp. and *Aulosira* sp. (Presscott, 1970) *Cosmarium*, *Phormidium, Symploca* (Zurita, 2005).

The impact of algae may be classified into two types, colorific changing and strength increasing. The obviously color of algae may also occur depending on the kind of organisms and on the cycle phase which causing worsen visibility. Algae could be ranging in color, light green to dark green, brown, grey, pink colored patinas. Some cases a reddish staining of marble (Praderio et al., 1993).

Algae were commonly investigated on many heritage materials as stones, mable, timber, plaster and the others (Schiraldi, 1995). Their presence not only darken and disfigure the exterior surfaces but also weaken the materials on which they grow. It have been found that the algae can produce and secrete a variety of metabolic products, among which predominate organic acids such as lactic acid, oxalic acid, succinic acid, glycolic acid and pyruvic acid. These organic acids can either directly dissolve sandstone or increase their solubility (Chiraporn Aranyanark, 1999). Moreover, the desiccation of the algae coating causes exfoliation of stone particles to which the algae were attached and dissolution of certain components of the stone. Hence, it was indicated that algae were contributed to mechanical deterioration.

Indirectly, algae can be considered to be pioneer organisms which might induce suitable substrates for other organisms (Schiraldi, 1995). Latterly, they can develop with just CO_2, N_2 and salt minerals traces. In fact they are, together with some very specialized bacteria, the only organisms capable to directly do nitrogen fixation (Witton et al., 1979). Algae also supported the colonization and development of an allied heterotrophic population of bacteria and fungi. Ultimately, after organic matter decomposition and humidification led to mosses and plants which could have higher deterioration potential than algae (Go’mez-Alarco’n et al., 1995).

2.3.5 Plant

Primary vegetal colonization of mineral substrata usually originates from more primitive lower plants which have a much greater capacity to extract mineral ions from "unavailable" sources such as rock surfaces (Saiz-Jimenez, 1995).

Some of lower plants as moss and liverworts can develop on stone and bring about the accumulation of atmospheric particles. The capacity of mosses to accumulate Ca^{2+} ions could be related with a biodeterioration capacity (Keller and Frederickson, 1952).

Besides, the growth of higher plants over monuments and historic buildings is one of major problems. These plants have been related to cause physical as well as chemical damage (Mishra et al., 1995). Trees and shrubs adjacent to the heritage buildings or wall can be referred to as resulting from the “umbrella” effect or their shadows from branches which have greater capacity to derive moisture through their root (Bellinzoni et al., 2003) causing breaks and fissures on surface of historical building.

The effect of plants on cultural resources are varied that depending on the vegetation zone and the type of cultural resources present (Randrup et al., 2001) especially genus *Ficus* of family Moraceae. The more common species are papal (*F.religiosa*) and banyan (*F. benghalensis, F.mollis, F.rumphii* and *F.scandens*) which has 1,000 species approximately. Most of them are tropical and evergreen plants which differ greatly from one another. *Ficus* roots like epiphytic orchid roots. It has the ability to withstand periods of low moisture.Thus, *Ficus* can growth on old building, tombs, dry rock and often entirely covering their stems. These growth of *Ficus* causing mechanical damage to old building and rocks (Husain and Datt, 2005). Otherwise, predominant plants that were revealed that encountered with historical building are following in Table 2.5.

Table 2.5 List of species encountered with the building (Spennmann, 2006)

Species	Ground, growing up wall	Out side wall	Flat roof over-hang ledge moist inner wall	Cracks on drier walls
Alysicarpus vaginalis (L.) DC. (Fabaceae)			■	
*Axonopus compressus (Sw.) P. Beauv. (*Poaceae*)*			■	
Chamaesyce hirta (L.) Millsp. (Euphorbiaceae)			■	
Chromolaena odorata (L.) King & Robinson (Asteraceae)			■	
Chrysopogon aciculatus (Retz.) Trin. (Poaceae)				
Cyanthillium cinereum (L.) H. Rob. (Asteraceae)				
Davallia solida (G. Forst.) Sw. (Davalliaceae)		■	■	
Ficus tinctoria G. Forst. var. *neo-ebudicum* (Summerh.) Fosb. (Moraceae)		■		
Fimbristylis dichotoma (L.) Vahl (Cyperaceae)			■	
Ipomoea triloba L. (Convolvulaceae)			■	
Microsorum scolopendria (Burm. f.) Copel (Polypodiaceae)		■	■	
Pennisetum purpureum Schumach. (Poaceae)				
Phyllanthus tenella Roxb. (Phyllanthaceae)				■
Pilea microphylla (L.) Liebm. (Urticaceae)				■
Piper ponapensis C. DC. var. *trukensis* (Yunker) Fosb. (Piperaceae)	■			
Psidium guajava L. Guava (Myrtaceae)				
Pteris vittata L. (Pteridaceae)				■
Mosses (at least 2 species)				■

Besides, relying on the climate regions, some case which were investigated in tropical zone as mosses, liverworts, selaginella, ferns and the flowering plants which shown by the data were presented bellowing, also causing impact to historical heritage,

Family Compositae : *Eclipta prostrat*a Linn., *Tridax procumbens* Linn., Family Euphorbiaceae : *Euphorbia hirta* Linn., Family Moraceae : *Ficus religlosa* Linn., Family Cucurbitaceae ; *Coccinia grandis* Linn., *Mukia maderaspatana* Linn., Family Acanthaceae ; *Ruellia tuberos*a Linn., Family Amaranthaceae ; *Gomphrena celosioides* Mart., *Amaranthus gracilis* Desf., Family Commelinaceae : *Commelina bengalensis* Linn., Family Cyperaceae : *Cyperus brevifolius* Hassk., Family Apocynaceae : *Catharanthus roseus* G. Don, Family Umbelliferae : *Centella asiatica* Urban., Family Malvaceae : *Abutilon indicum* Sweet, Family Mimosaceae : *Mimosa pudica* Linn., Family Rubiaceae : *Digitaria adscendens* Henry, *Chloris barbata* Sw., *Eragrostis zeylanica* Nees & Mey, *Dactyloctenium aegyptiacum* Willd, *Cynodon dactylon* Pers., Family Moraceae : *Ficus rumphii* Bl., *Ficus microcarpa* Linn., *Ficus benjamina* Linn. (Akorn Sripleng, 1995).

2.3.6 Insect

Insects pests use the heritage material habitat or nutrient source. It causing varied problems of the heritage material deterioration, not only in organic materials like, timber, fabric, paper but inorganic material like, mortar, plaster and brick. It could be affecting on cultural heritage and art objects in many characterization such as Figure 2.22, 2.23.

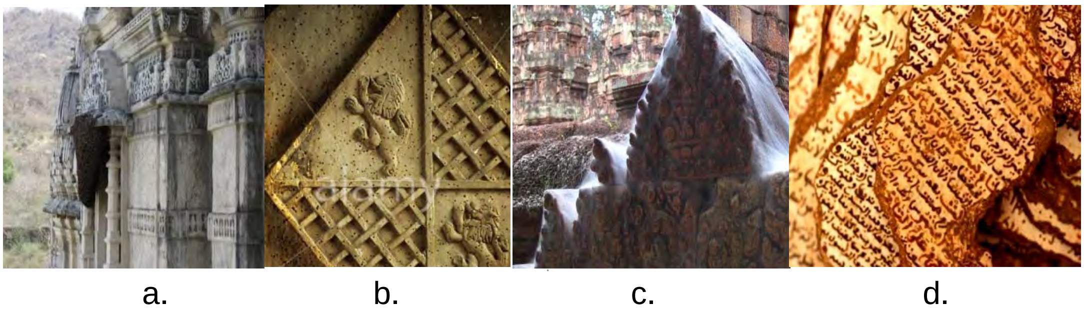


Figure 2.22 Some characteristic of the historical heritage deterioration by insect : a. Ranakpur jain temple, India (Diane, 2007) b. Historic heraldic wooden panel, United Kingdom (Alamy images, 2006) c. Tympanum, Banteay Srei, Cambodia (Bill and Heidi, n.d.) and d. Ancient Koranic Manuscript, library of Ouadane, Mauritania. (Belani, 1998)

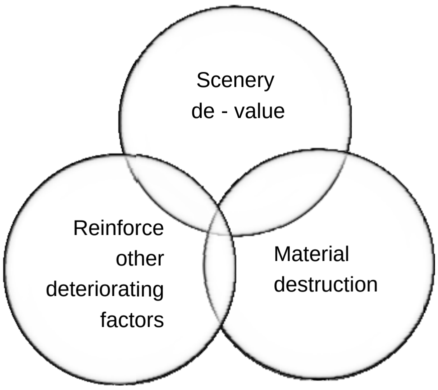


Figure 2.23 The deteriorated characterization of biotic factors on cultural heritage

Scenery impact, reinforce other factors and material destruction of artfact heritage were concerning with many insect species. Widely investigated were revealed the organism species causing deterioration on cultural heritage materials, were called, “The dirty dozen of museum pests” as described in Figure 2.24 which showing eleven species from twelve dominant species.

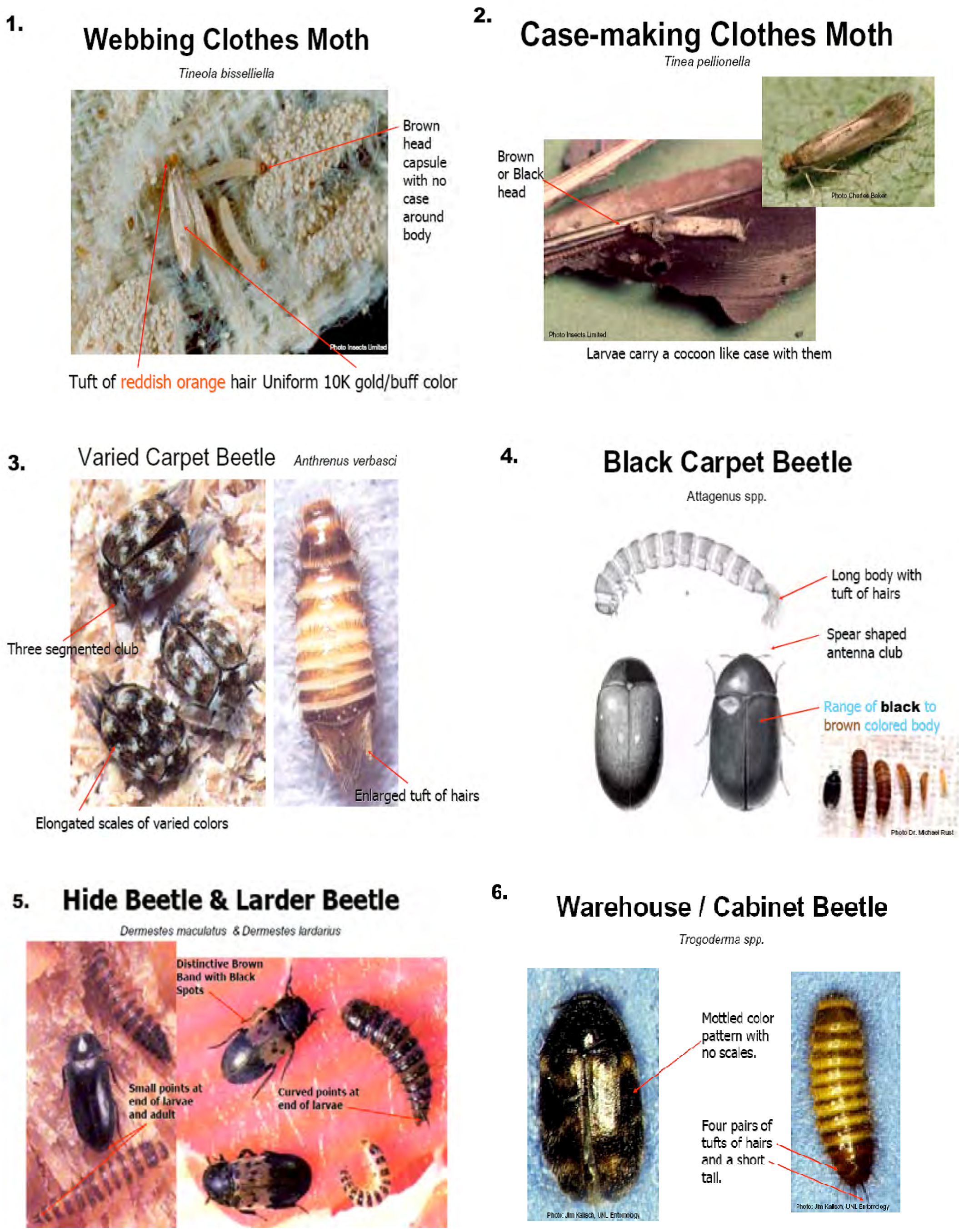


Figure 2.24 The dirty dozen of museum pests (Modified from Insect Limited, Inc., 2008)

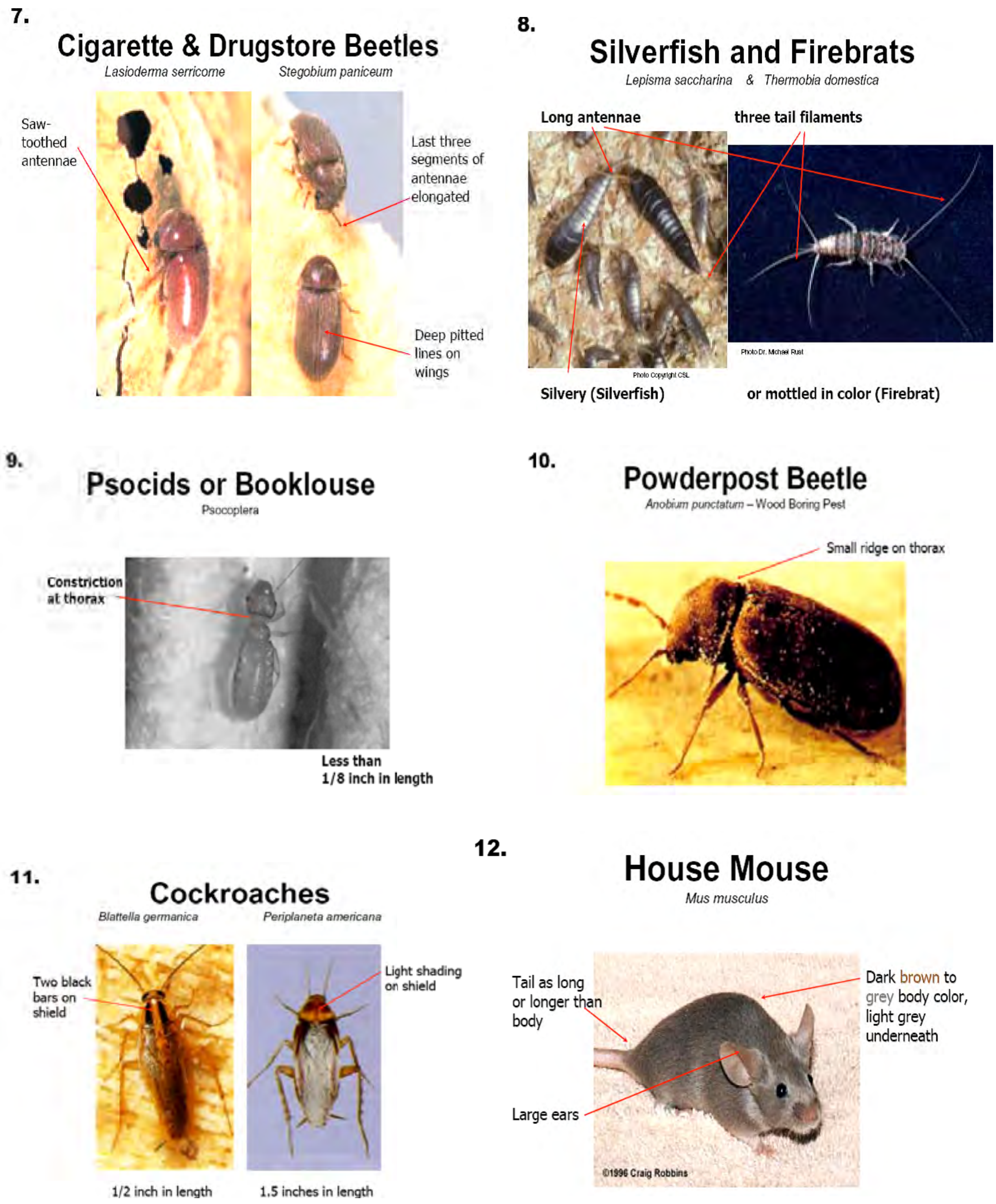


Figure 2.24 The dirty dozen of museum pests (Modified from Insect Limited, Inc., 2008) (Cont.)

The other common insect pests which were found causing deterioration on heritage objects also including Odd beetle *(Thylodrias* sp.*)* (Koesler et al., 2000) *Coptotermes havilandi, Heterotermes* sp*.* (Su et al., 2002) and termite *(Reticulitermes* sp.) (Koestler et al., 2000; Clausen and Yang, 2007 ; Gambetta et al., 2000)*.*

Termites have been admitted that they are causing severe deteriorated problems on wooden heritages (Figure 2.25) and predominant insect species that have to monitor carefully (Table 2.6).

Figure 2.25 The wooden cultural heritage deterioration by termite : a. termite and b. The Fragile painted mask of a wooden coffin, Egypt's Valley of the King, badly damaged by termites (Carter, 2008)

Table 2.6 Insects frequently found on wooden materials (Allsopp and Seal, 1986)

Order	Family	Common names	Type of damages
Coleoptera	Anobidae	Furniiture beetles	Winding and circular tunnels; circular emergence holes
	Lyctidae	Powderpost beetles	Tunnel with oval section
	Botrychidae	Wood borer	Circular holes and tunnels
	Cerambycidae	Longhorn beetles	Large, oval tunnels and holes
Isoptera	Kalotemitidae	Termites (white ants)	Deep and crater-shaped holes. Sometimes entire interior of object is destroyed but outer surface is left intact
	Rhinotemitidae	“	“
Hymenoptera	Siricidae	Wood wash	Circular tunnels and holes of wide dimension

Moreover, many insects species use heritage building like their residence such as spiders and bees also often found in cultural heritage. Despites, they could not destroy the material but mostly, they causes scenery devalue effect and sometime could induce other organisms, as microorganism, animals, altogether weeds or plants to the heritage. Then, it might be more affecting on the heritage, afterwards.

2.3.7 Bird

Any bird can be considered a pest if it is damaging a building (NYC, 2009). Those birds will be into the general category of "pest bird" species (Abouzeid et al., 2007). Due to the birds causing problems in a variety of way, it has been many documented transmissions of the species of birds that could damaged on the building, but majority species of the birds which were known to pose a significant problem on historic buildings are (Historic Scotland, 2008),

- Pigeons (*Columbia livia*)
- House Sparrows (*Passer domesticus*)
- Seagulls (*Larus argentatus*)
- Starlings (*Sturnus vulgaris*)

The deterioration problems from birds can be concluded by following (Figure 2.26) (Historic Scotland, 2008),

- Droppings has a negative impact on the visual appearance.
- Feathers, droppings and dead birds can block rainwater, leading to a variety of related problems.
- Nests and droppings can act as a breeding ground for bacteria and insects posing a health risk to the occupants of buildings,
- Bird droppings are acidic in nature which cause long term deterioration. On reaction with moisture or water this can produce a mould which can attack masonry, bird droppings

are also highly corrosive to metal, and this can cause severe damage to statue and memorials such as limestone and calcareous sandstone (Tümer, 2003).

- Droppings can make pavements slippery, hazardous and some cases the material structure be broken by dropping weight.
- There is a potential allergen risk to humans which can cause respiratory and skin problems. The removal of excrement poses problems of both safety and of process and some of these are still discussed (Channon, 2008)
- Birds can also be carriers of diseases for heritage worker and visitors, especially pigeons are known to harbor 60 different diseases (Weber, 1979).
- Arthropods are vectors of entomogenous fungi and play an important role in caves, catacombs and mural paintings (Jurado et al., 2008).

Figure 2.26 Bird impact on cultural heritage : a. Asakusa temple, Japan (Creative commons, 2002) and b. Robert Adam's Pultney Bridge, Bath (Taylor cited in Abouzeid et al, 2007)

2.3.8 Human

Many problems in our society arose from the lack of awareness and responsibility of cultural heritage. Anthropogenic pollution is important factor influencing the deterioration (Herrera and Videla, 2004). There were classified in Figure 2.27 (modified from Cultural & Natural Heritage, 2008).

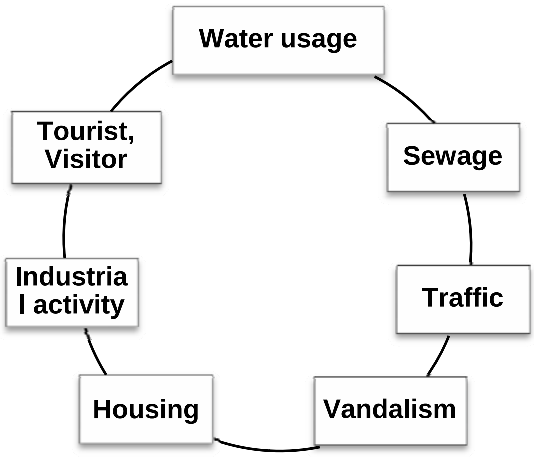


Figure 2.27 Anthropogenic factors affecting cultural heritages

Water Drinking water distribution networks in historic areas are often exhausted and in very bad condition. Leakage contributes to a rise in sub-surface water to the extent that in many parts of historical building. Water is less than a meter below the surface and in some cases water percolates to the surface.

Sewage Leakage of sewage water leads to a contamination of subsurface water and thus increases the potential of chemical decay, especially of the foundations of building.

Traffic Vibrations from heavy traffic and exhaust fumes also contribute significantly atmospheric pollutants.

Vandalism People who live within archeological and historic site are a serious problem. This case is the conflict between government agency and those people. The people refused to move out from the archeological heritage. Therefore, historic and archeological sites which are highly prone to loss tend not to perceived as heritage in the general view. Nowadays, many case of trespass or damage to the physical remains still occur all the time, both as a result of ignorance or intentionally (ICOMOS, 2000).

Housing Deterioration of urban aestheticism historic and archeological areas is often due to the construction of modern buildings that do not match the ancient ones is form, color or appearance. In many area, buildings have appeared that they have no architectural like to either the local environment or the architectural features of heritage of the area.

Industrial activities Combustion, transportation systems and construction can pollute the atmosphere and also have the effect to mechanical properties of soil. Maybe it could alter the surrounding systems such as water flow, causing the impact on historical buildings.

Visitor and tourist It was found that 37% of the global tourism has a cultural motivation. Cultural heritage is the greatest extent as support for its backbone activities (Archimedes programme, n.d.). Tourism has a direct negative impact such as transportation of external particulate matter and the main problem is that microclimate has been planned for the well being of visitors during only the visiting time (Camuffo et al., 2001). The heat and the moisture released by people also impact to historical building (Figure 2.28) (Camuffo et al, 2004). The UNI regulations put forward a set of parameters which can significantly influence the degradation processes of work of art are visiting timetable and daily number of visitors

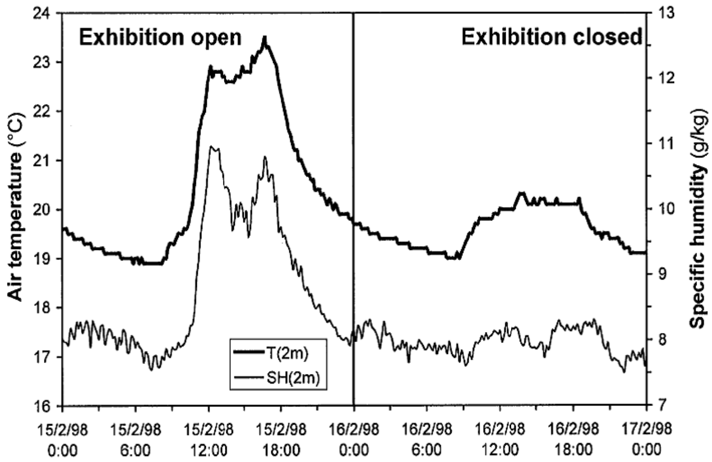


Figure 2.28 Diurnal variability of the air temperature and of the specific humidity in the Kunsthistorisches Museum measured during a special exhibition in February, 1998 (Camuffo et al., 2001).

The effect of mass tourism is evident from the comparison of closing and opening days (Figure 2.28). Moreover, it was found that the accumulation of dust on artifacts could led to a rather disfiguring appearance. Furthermore, nicotin presented in cigarette smoke can also adhere to surfaces of objects to cause a pronounced discoloration (Heritage Conservation centre, 2001).

In addition, Increasing numbers of visitors entering building can put pressure on the structures and may inadvertently damage portable elements (Lazer, 2006). There are still found hydrogensulfide (H_2S) were emitted from a museum visitors by a variety of human mechanism and the effect of these emissions on the indoor air quality of museum (Schieweck et al., 2005).

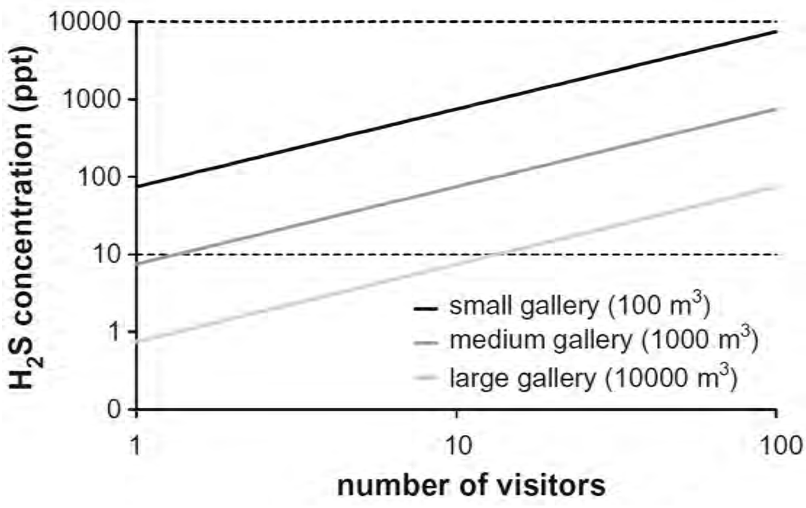


Figure 2.29 The input of H_2S by visitors as a function of the gallery sizes (Ankersmit et al., 2005)

2.4 Site study description

Sichang is important and well known island over hundred years ago that has nature reserve followed by Thailand cabinet conclusion, sixth from twenty - four places of the Eastern in Thailand. This area has stunning scenery and beautiful beaches including to historical attractions especially Chudhadhuj royal palace of King Chulalongkorn, Rama V. The place is not only the first summer royal palace but also only one palace in the sea of the Chakri dynasty.

From historical evidences it is found that before the royal palace was built, King Mongkut, Rama IV, was the first monarch who visited Sichang island by his private steamship, Siam Orasumpol. But he did not built any residences on the island. By the reign of his son, His Majesty King Chulalongkorn, Rama V (Figure 2.30), Sichang island had grown considerably because merchant seafarers used it 0r storm shelters as port for exchanging and transferring the goods.

Owning to Sichang island have pleasant surroundings and suitable for recreation, King Chulalongkorn, Rama V sent his son, His Royal Highness Prince Vachiravudh (later King Rama VI) (Figure 2.30), to recuperate his sickness. Then Sichang island became to be the popular recreational area for convalescent member and noblemen.

In 1891, King Chulalongkorn decided to establish the summer royal palace and a temple on Sichang island which was designed by his brother, Prince Narissaranuwattiwong in terraced - garden style that had been influenced by Italian - Renaissance architecture. Altogether the palace was managed the construction by Prince Panuphanwongworadej. Everything in the palace had named melodiously by King Chulalongkorn. For instance, the residences included Kosiwasuphan, Manthat Rattanaroj, Chottirotprapha and Mekkhalamanee.

In 1893, His Majesty King Chulalongkorn and Her Majesty Queen Saovabha Phongsri (later Her Majestry Queen Sri Savarindra) (Figure 2.31) who was pregnancy dwelled on Sichang island. After that, on July, 5th, the queen gave birth to a prince who was named Prince Chudhadhuj Dharadilok (Figure 2.31). Later on 10th of August, King Chulalongkorn celebrated a month old prince ceremony, The King approved to give the palace’s name honorably, Chudhadhuj royal palace.

However, the political crisis occurred in R.E. 112 (1893 A.D.). The crisis led to set up blockade in the gulf of Thailand by Frence gunships. The crisis caused Sichang island unsafed from the enemies, therefore Chudhadhuj royal palace had abandoned since then. Untill 1900, King Chulalongkorn had commanded to pull down the main building, Manthatrarattanaroj throne which made of golden teakwood thorne to assembled in Suandusit royal palace in Bangkok, the capital of Thailand. The throne was renamed Vimanmek throne.

Nowadays, Chudhadhuj royal palace has only four residences and a temple afterwards, consists of Wattana residence, Phongsri residence, Aphirom residence, Green wooden residence includeing Aussadangkhanimit Temple. The first three residences used to as convalescent residences called Asaiyasathan, available for both Thais and foreigners. Later, in 1907, King Chulalongkorn allowed to use partly area of Chudhadhuj royal palace for children - bridewell but did not remain in the reign later. Until 1940, the Royal Thai Police Department, Ministry of Interior be permitted to use the area for foreigner detection.

In world war II, the ministry of communications used this palace in order to transportation foodstuffs to Japan faction also the palace became the local government school in 1945. Later, Chudhadhuj royal palace still used for the Sichang official place several times irrespective of use for district office , post office , department of rice - grains office and the others.

In 1977, Chulalongkorn University received authority from the Treasury Department to establish the Marine Science Research

Institute and Student Training Institute. Chudhadhuj royal palace have been resuscitated continuously which finally it has been developed to museum. The ceremonial opened by Her Royal Highness Princess Maha Chakri Sirindhorn on 12th January, 2004. The princess also presented her fund to help renovate Phongsri residence. Since then, it is the beginning of Chudhadhuj royal palace museum, important historical place on Sichang island.

The boundary of Chudhadhuj royal palace, 236 Rai have been operating followed by living cultural heritage initiation. It comprised dignified residences, pagoda, pond, bridge moors, lighthouse and the others. Even though, it has have continuously maintenance, the museum has confronted deterioration problems which concern with materials such as stone, lime mortar, lime plaster and wood.

Aforementioned problems should have to solve intentionally, possibly irrestorable problems. This dissertation require to obtain the knowledges about effect of environmental factors of study area which related to the deteriotation of Chudhadhuj royal palace and analyze those factors not only active conservation but also passive conservation for the purpose of restoration and urban conservation in order to Thai commonalty assemble with inherit Thai cultural heritage in a state of history, culture, architecture, nature, religion and spirit forever.

Figure 2.30 King Chulalongkorn, Rama V and Prince Vachiravude (Cultural Center of Chulalongkorn University, n.d.)

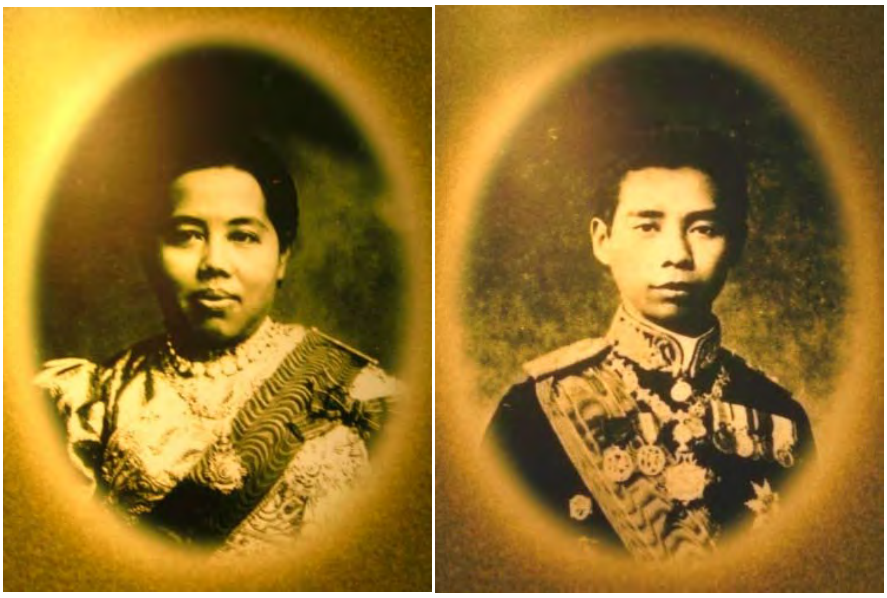


Figure 2.31 Queen Sri Savarindra and Prince Chudhadhuj Dharadilok (Cultural Center of Chulalongkorn University, n.d.)

CHAPTER III

PHYSICAL FACTORS AFFECTING DETERIORATION ON HISTORICAL STONE INSCRIPTIONS

3.1 Introduction

Aussadangkhanimit Temple (Figure 3.1) is located on the crest of Chulachomklao Hill, approximately 40 metres above sea level (Figure 3.2), in the south of the palace. It is a spherical pagoda, combined between Langka and Gothic style, including Lan Prataksin Terrace. Outside the mortal wall of the temple, there are eight stone inscriptions (Figure 3.3) with the Lord Buddha doctrine carved on each, situated at the corner of the octagonal pattern surrounding the temple. At present, the stones have been defacing by weather deterioration.

Figure 3.1 The Aussadangkhanimit Temple

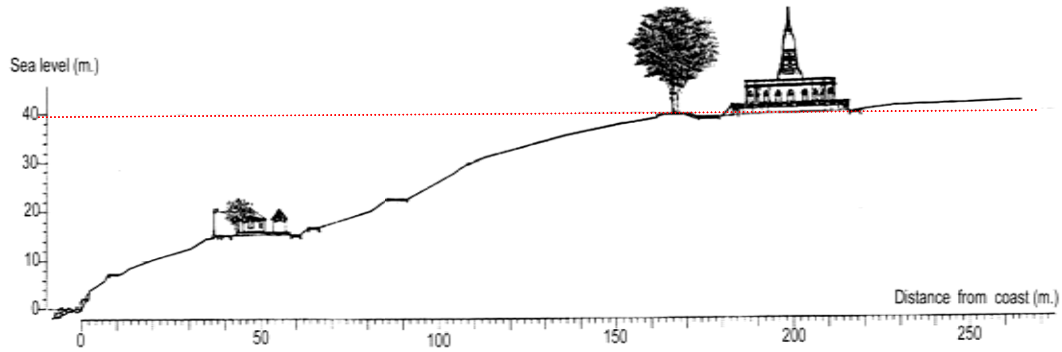


Figure 3.2 The Aussadangkhanimit Temple location (Modified from Chulalongkorn University, Faculty of Architecture, 2005)

Figure 3.3 A historical stone inscription situated outside the Aussadangkhaninit Temple

The deterioration of stone monuments are resulted by natural process which are accelerated if the monuments located nearby urban or industrial areas (Elgohary, 2008). The conservation and restoration of the stone heritages have been focused on three major categories, the first is determining sources of raw materials. The second is developing methods of authenticating stone artefacts and the last is the preservation (Newman, 2005). Besides, it was reported that the conservation had been extremely concerning on the meteorology, especially in the coastal area with dynamic oceanic physical factors.

Stone monuments located along coastal areas have been exposed to the main factors of stone weathering problems, such as rain, wind and temperature, including a peculiar impact from sea aerosols (Olivier et al., 2007; Cataldo et al., 2005). It was reported that the influence of the sea dominated in the stone weathering process (Torfs and Grieken, 1998). Marine aerosol is one of the most significant components that make up the atmospheric particulate. It intensifies the processes of weathering particularly in coastal areas through the effects of wet and dry depositions on the stone of monuments (Zezza and Macrì, 1995).

Stone decay takes many different forms. It depends on the composition of the stone and the particular surrounding environment (Grieken et al., 1998). Most common types of deterioration on stone cultural heritages in Thailand were reported as exfoliation, scaling and pulverization which were complex problems and required disciplines to plan appropriate strategies (Chiraporn Aranyanark, 1999).

3.2 Objectives

The aims of this study are to develop and to apply three - dimension (3-D) images processing technique that enable to analyze the weathering degree of the historical stone inscriptions surrounding the Aussadangkhanimit Temple which caused by light intensity and the positional arrangement of eight historical stone inscriptions.

3.3 Materials and methods

The analysis were consisted of four procedures as follows, to identify the stone composition, to develop the evaluation method for measuring light intensity, to study the effect of precipitation and salt, including to calculate the weathering degree of historical stone inscriptions from the data.

3.3.1 Stone mineral composition analysis

Two types of stone samples were analyzed for determining the mineral composition by X - Ray Diffractometer (Moroni and Pitzurra, 2008; Lopez - Arce et al., 2009; Pavia and Caro, 2006).

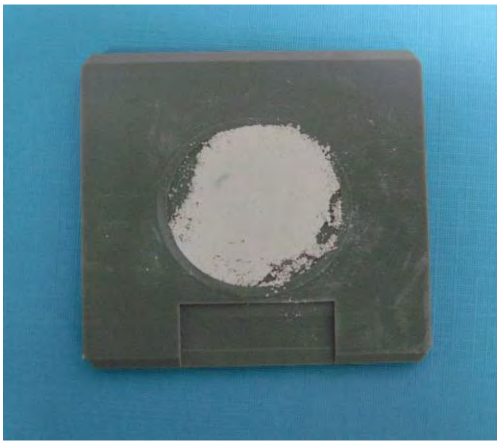
The first stone type was a small piece of stone naturally cracked from a historical stone inscription (Figure 3.4 a) and the second stone type was collected from an adjacent stone scattering around Chulachomklao Hill nearby the temple (Figure 3.4 b). Both stone samples were collected on 12 July, 2008.

a. b.

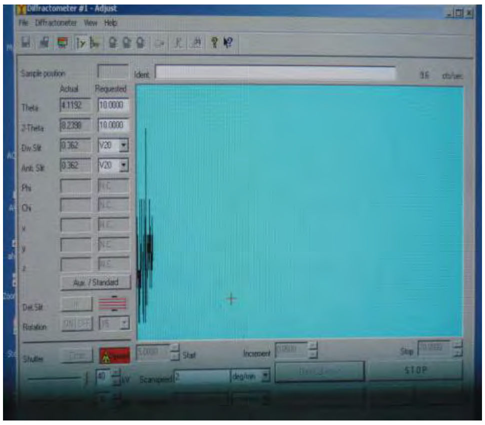
Figure 3.4 The stone samples : a. Stone naturally cracked from a historical stone inscription and b. Stone from an adjacent stone scattering around Chulachomklao Hill

The stone samples were brought from the study site (Figure 3.5 a). The stones were ground and the stone powder were packed in the test plates (Figure 3.5 b). After that the test plates were put in X - Ray Diffractometer (XRD) : model D8 ADVANCE (Figure 3.5 c). The analyzes were proceeded under the condition as : XRD scan speed at 5 dec/ sec., Type : 2Th/Th locked, Start 5.000^{o} - End 70.000^{o}, Step : 0.050^{o} and Step time: 1.5 s at 25^{o} C for 1 hour.

After that, the diffractogram of the stone samples were analyzed for their mineral compositions by comparing the sample diffractogram with standard diffractogram database (Figure 3.5 d).



a. b.



c. d.

Figure 3.5 Mineral composition analytical steps of stone samples by X - Ray Diffractometer : a. Stone grinding b. Stone powder packing c. X – Ray scattering and d. Sample diffractogram

3.3.2 Effect of precipitation and salt on limestones used for carving the inscriptions

Preliminary results from XRD data, the diffractograms indicated that major mineralogical compositions from two samples types were related. It could be assumed that the historical stone inscriptions and the adjacent stone were identical. Two stone samples were categorized as a kind of limestones.

The procedure was undertaken in order to prove suspicions by accelerated weathering tests on the porous stones (Van et al., 2007).

a. b.

Figure 3.6 Stone samples : a. raw sample and b. cut and polished samples

An adjacent hill stone was chiselled (Figure 3.6 a). The bulky stone was cut into pieces of stone samples, rectangle sized 2 x 4 x 1 cm^3 (Figure 3.6 b). Next, the stone samples were separated into three groups. Each group was treated by simulating cycles as Table 3.1 (Haynes et al., 2008; Warke and Smith, 2007). This study was carried out in laboratory and focused on the sea salt affecting on the limestones.

Table 3.1 Stone - weathering accelerated cycles

Group	**Simulating exposed environment (1 day = 1 cycles)**
1	Ambient condition (control group)
2	Sea water soaking - Ambient condition
3	Rain soaking - Ambient condition

This experiment was conducted to study the effect of salt on limestone samples. Weathering cycle method was taken by exposed the stone samples to the seawater (McCabe et al., 2007). The second stones group was soaked into sea water for an hour then the samples were laid down under ambient condition until 24 hours (1 cycle). These method was followed as in Andriani and Walsh (2007), but sea water was used instead of 14% sol of $Na_2SO_4 \cdot H_2O$.

To compare the effect of precipitation and salt on limestone samples, rain weathering cycles were conducted on the third stone group like the salt weathering cycles but rain water was used instead of sea water. The cycles experiment was continually repeated for three months. Later, the weathering characteristic of limestone samples was evaluated by visual assessment and X - ray diffraction.

3.3.3 Technical development to estimate light intensity on historical stone surface

The methodology of approach presented here was based on digital image processing (Fulvio, 1990). Spatial - temporal analysis had been taken, respectively, as the flow chart, Figure 3. 7.

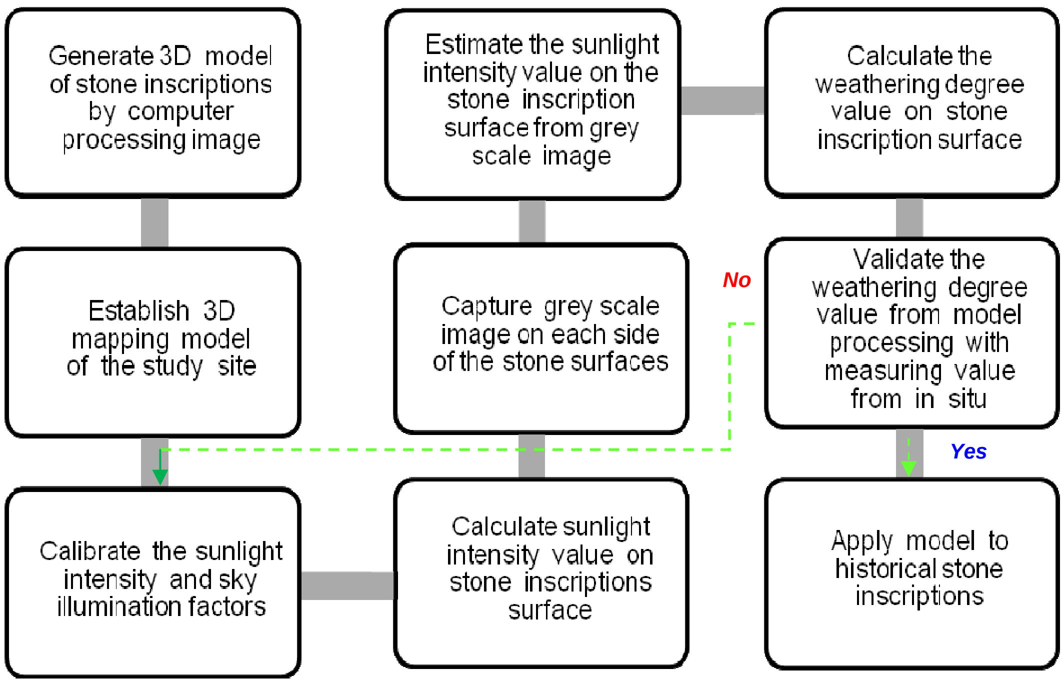


Figure 3.7 Flow chart illustrated the steps of spatial temporal analysis process

First of all, some photographs of two dimension images of the stone inscriptions were taken with calibrate plate (Rozenbaum et al., 2007). Intentionally, the photographs of the inscription were taken thoroughly in varied angles, then the 2D images were input to generate 3 dimension models of cultural heritage by software (Gruen et al., 2004). as Figure 3.8.

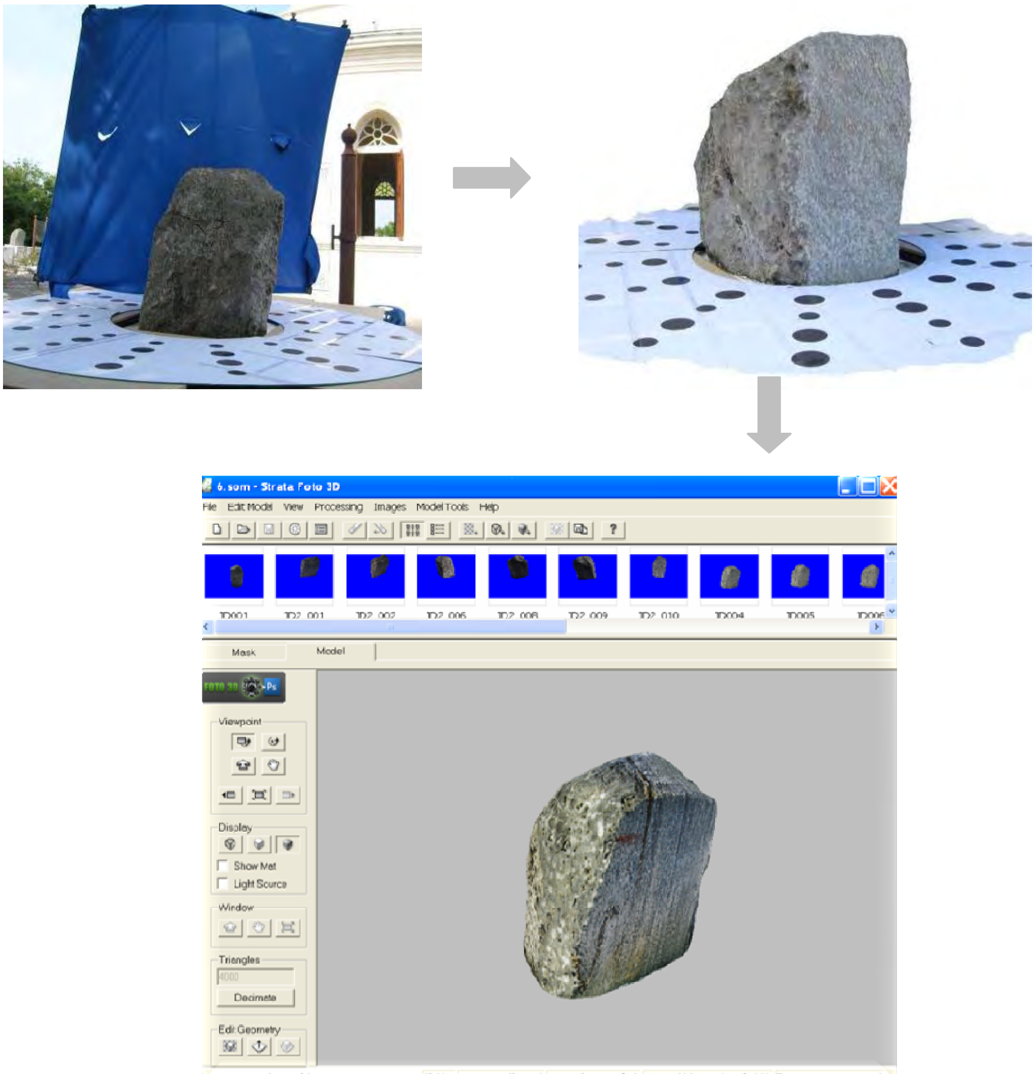


Figure 3.8 3D image preparation for spatial temporal analysis

The next step, 3D mapping model of the study site, Aussadangkhanimit Temple, was simulated. The sunlight intensity and sky illumination factor process were calibrated. Afterwards, these factors were used to calculate sunlight intensity on stone inscription surface by application program.

Later, computational analysis process was used to create grey scale or grey - level images to represent the weathering forms by rendering light on each side of the stone inscription surface for estimating the sunlight intensity value (I) (Figueiredo et al., 2007; Maurício and Figueiredo, 2000; Rossi et al., 2004).

Light intensity values of all four sides of a stone inscription (I_i) were recorded and the maximum values from all of the values were used as the maximum light intensity (I_{max}). Then the weathering degree values were calculated by the following equation (3.1)

$$\mathbf{WD = I_i / I_{max}} \quad \text{---------} \quad 3.1$$

When WD_i : weathering degree

I_{max} : maximum light intensity

I_i : light intensity

(when i = 1 = left side, 2 = right side, 3 = front side, 4 = back side)

To confirm the spatial - temporal model, the weathering degree data from model processing measured from in situ were validated. This step, the inscription number 6 was chosen for the representative of all inscriptions because it is situated at the open area that had not been disturbed by un-interested factors such as shading from trees or the pagoda.

Light intensity data on each side of stone inscription number 6 were monitored for meteorological condition on 4 December, 2008 because of the clearly sky in that day.

Unless the validation was uncertainty, the validation step was repeated to adjust the calibration factors until the spatial temporal model was acceptable. The model was applied to the other historical stone inscriptions by entering the data, time and calibrated factors into software. The sunlight was rendered to the stone object and the enumerated process was imitated.

3.3.4 Estimation the weathering degree of historical stone inscriptions by 3D image processing and spatial - temporal analysis

The light exposure on the historical stone inscriptions was estimated, and these results were used to calculate the weathering degree of the historical stone inscriptions using the method developed as already approved in topic 3.3.

Three months (April, September and December in 2008) were selected as the time period for entering to the program. These months were representatives of the Sichang island seasons. Sichang island was reported to have three seasons : sunny, rainy and windy. Sunny season was from March to June. The maximum temperature was in April. Rainy season was from July to October with the maximum rainfall in September and windy season was from November to February with the maximum wind velocity in December (Thai Meteorological Department, 2007).

Later, the whole data from the four sides of the stone inscription on left, right, front and back sides were summarized. Total sunlight intensity on each side at a certain time was estimated using equation 3.2.

Total light intensity at time t $I_t = \sum_{i=1}^{4} I_{t,i}$ ------------ 3.2

(when i = 1 = left side, 2 = right side, 3 = front side, 4 = back side)

Total light intensity at time, t of each stone was summarized again to represent as total light intensity (I) using the equation (3.3),

$$\textbf{Total light intensity } I = \sum_t I_t \quad \text{------------------} \quad 3.3$$

(when I_t is Total light intensity at time, t)

3.4 Results

3.4.1 Stone mineral composition analysis

Primarily, the mineral composition were analyzed by XRD. The X - ray diffractograms indicated that both stone samples, historical stone inscription and adjacent stone sample, were similar (Figure 3.9, 3.10 and 3.11). Both of them composed of three main mineral compounds : calcite ($CaCO_3$), actinolite [$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$] and calcium silicate ($CaSiO_3$).

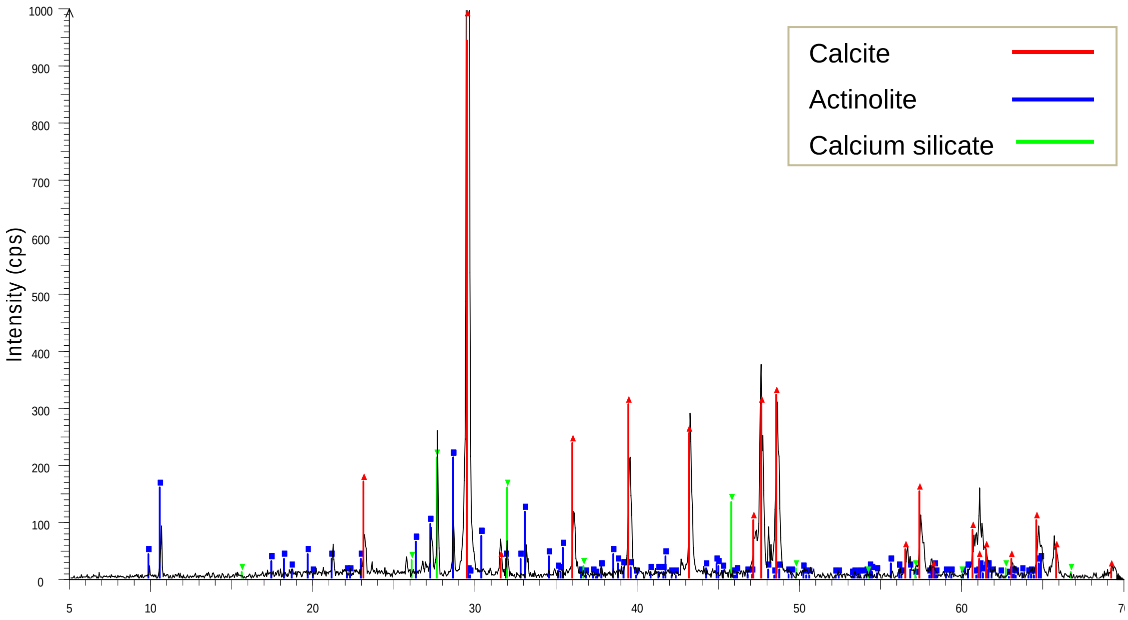


Figure 3.9 The diffractogram of historical stone inscription sample

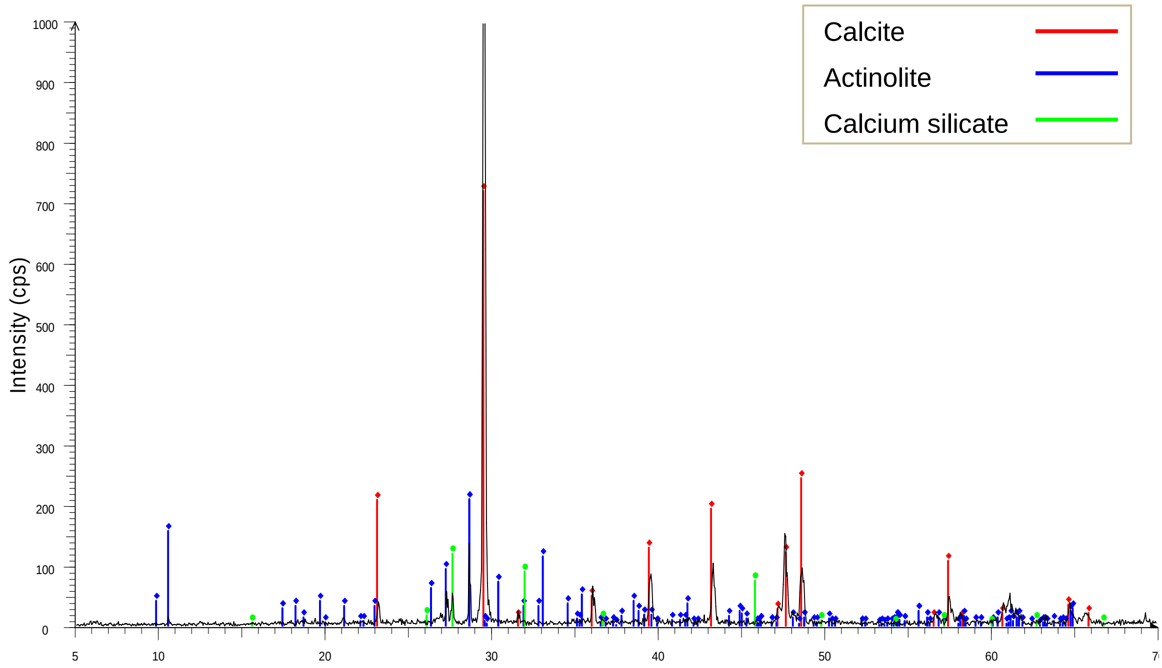


Figure 3.10 The diffractogram of adjacent stone sample from Chulachomklao Hill

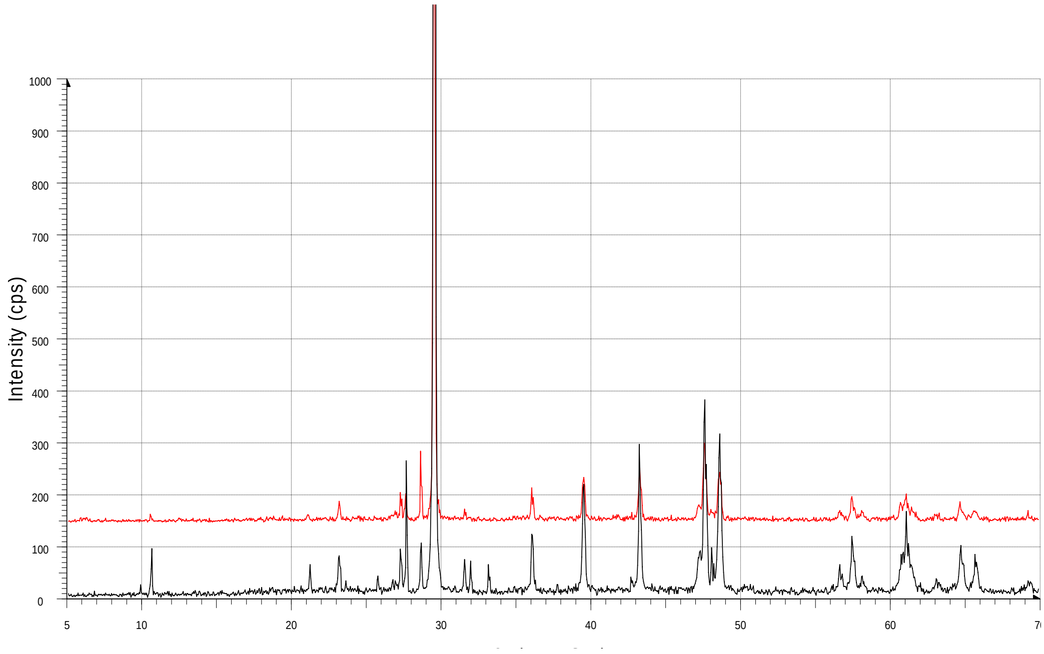


Figure 3.11 The diffractogram showed the similarity of peak patterns of stone samples from the stone inscription (black line) and the adjacent hill (red line)

3.4.2 Effect of precipitation and salt on limestones used for carving the inscriptions

The stone samples treated by accelerated cycles, sea water and rain water were assessed by visualization. It was rarely found any presence of white crust and/or white powder on the surfaces of the samples that immersed into sea water when drying. The white powder on the sample surfaces could dissolve when the stone as soaking in sea water. The white crusts were swabbed by cotton sheet, 5 x 6 cm^2 which saturated with deionized water 2 cm^3 then squeezed the solution from the cotton sheet into the test tube and measured salinity value using salinity meter.

a. b. c.

Figure 3.12 The deteriorated characterization from accelerated cycles : a. rain water - ambient condition b. ambient conditon (control group) and c. marine water - ambient condition

The result was taken by visual assessment comparing among the three groups (Figure 3.12). Comparing to the control group, the stone group treated by soaking in rain water was slightly darkening, whereas the most darken was in the group treated by sea water. The latter group had brown dispersing spot noticeably. Likewise, this result was found as similar spots occurred on the surface of every historical stone inscriptions at Aussadangkhanimit Temple (Figure 3.13).

Figure 3.13 Historical stone inscription surface

When the experimental cycles had finished, the mineral composition of stone samples were analyzed using X-Ray Diffractometer (XRD). Diffractogram of the sea water - ambient condition cycles (Figure 3.14) showed that prominent components consisted of Calcite ($CaCO_3$) Actinolite [$Ca_{2\,-}(Mg,Fe)_5\ Si_8\ O_{22}(OH)_2$], Silicon (Si), Sodium Calcium Silicate ($Na_2Ca\ -SiO_4$) and Albite,calcian, orderd [$(Na,Ca)\ Al\ (Si, Al)_3O_8$].

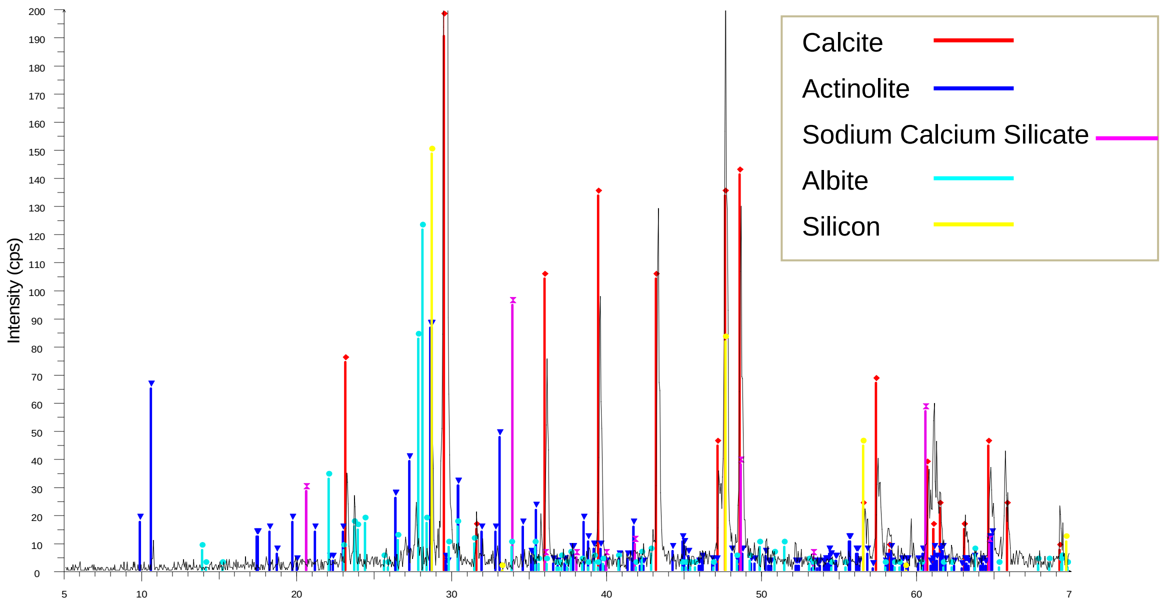


Figure 3.14 The diffractogram of stone samples : Sea water - Ambient condition cycles

Mineral compounds of the stone exposed to rain water - ambient condition cycle (Figure 3.15) consisted of Calcite ($CaCO_3$), Actinolite [$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$] and Calcium Silicate (Na_2CaSiO_4).

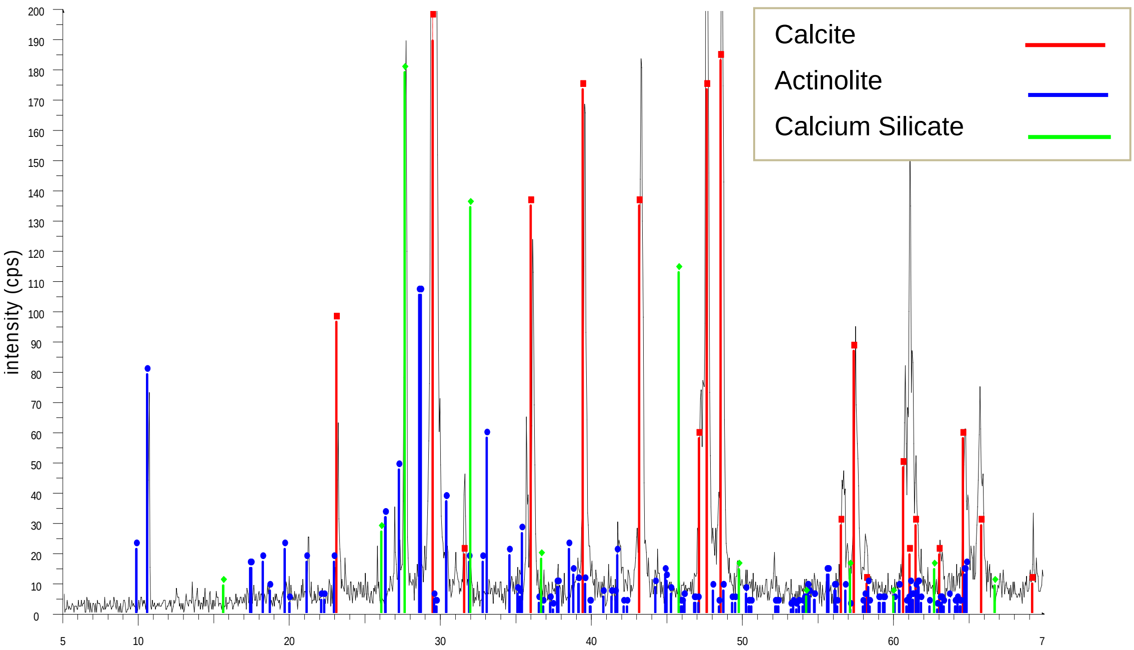


Figure 3.15 The diffractogram of stone : Rain water - Ambient condition cycles

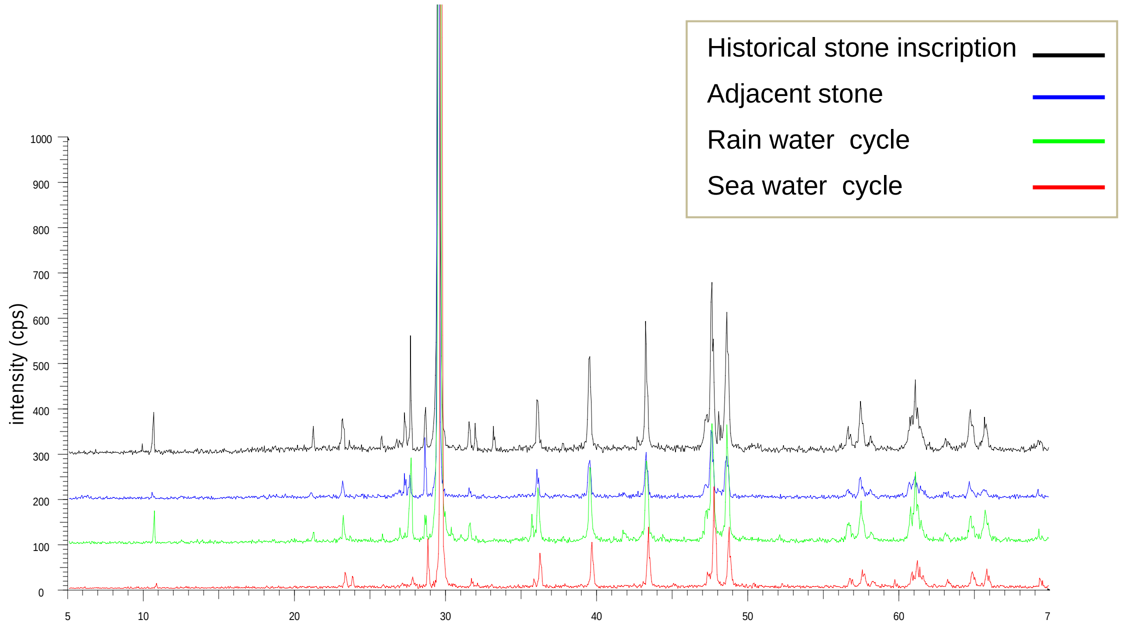


Figure 3.16 The diffractogram showed the comparison of peak patterns of stone samples from the historical stone inscription, adjacent hill stone, simulation cycle stones, both in rain water and sea water treatments

The diffractograms compared among four stone groups such as antique historical stone inscription (Figure 3.16, black line), adjacent hill stone (Figure 3.16, blue line), stone samples in simulation cycles, both rain water (Figure 3.16, green line) and sea water treatments (Figure 3.16, red line) were resemble in prominent mineral composition. But only the group of the stone in sea water treatment was slightly different.

3.4.3 Technical development to estimate sunlight intensity on historical stone surface

Simulation of the historical stone inscriptions arrangement around Aussadangkhanimit Temple was generated by 2D image processing. The shape and proportion of the simulated map were similar and represented to the authentic stone inscription.

Calibration factors which was generated to input into software as followed,

Sun intensity factor = 2,

Sky illumination factor = 0.5

For more accuracy, these factors were used to estimate light exposure by application program.

Table 3.2 The light intensity estimated by spatial - temporal analysis

Side / Time	Left		Right		Front		Back	
	I_i	$\pm\Delta I_i$	I_i	$\pm\Delta I_i$	I_i	$\pm\Delta I_i$	I_i	$\pm\Delta I_i$
09.30.00	26.82	33.39**	127.88	13.9	212.16	0.36	11.00	0.00
10.45.00	174.22	5.86	15.00	0.00	206.00	0.00	14.00	0.00
11.45.00	199.64	2.07	15.74	0.46	192.77	0.56	15.00	0.00
14.30.00	216.76	0.45	12.00	0.00	36.51	0.55	12.00	0.00
14.45.00	216.96*	0.22	11.00	0.00	42.55	0.51	12.00	0.00
15.15.00	216.55	0.51	10.00	0.00	49.48	0.52	10.00	0.00
15.30.00	215.96	0.19	9.00	0.00	52.53	0.50	9.00	0.00

I_i = Sunlight intensity on each stone, estimated by spatial - temporal analysis (Grey scale) ; ***** = I_{max}, ** = high inconsistency of surface

Table 3.3 The weathering degree estimated by spatial - temporal analysis

Side / Time	Left		Right		Front		Back	
	WD_i	$\pm\Delta WD_i$	WD_i	$\pm\Delta WD_i$	WD_i	$\pm\Delta WD_i$	WD_i	$\pm\Delta WD_i$
09.30.00	0.124	0.154**	0.589	0.064	0.978	0.002	0.051	0.000
10.45.00	0.803	0.027	0.069	0.000	0.949	0.001	0.065	0.000
11.45.00	0.920	0.010	0.073	0.002	0.889	0.003	0.069	0.000
14.30.00	0.999	0.002	0.055	0.000	0.168	0.003	0.055	0.000
14.45.00	1.000	0.001	0.051	0.000	0.196	0.002	0.055	0.000
15.15.00	0.998	0.003	0.046	0.000	0.228	0.002	0.046	0.000
15.30.00	0.995	0.001	0.041	0.000	0.242	0.002	0.041	0.000

** = high inconsistency of surface

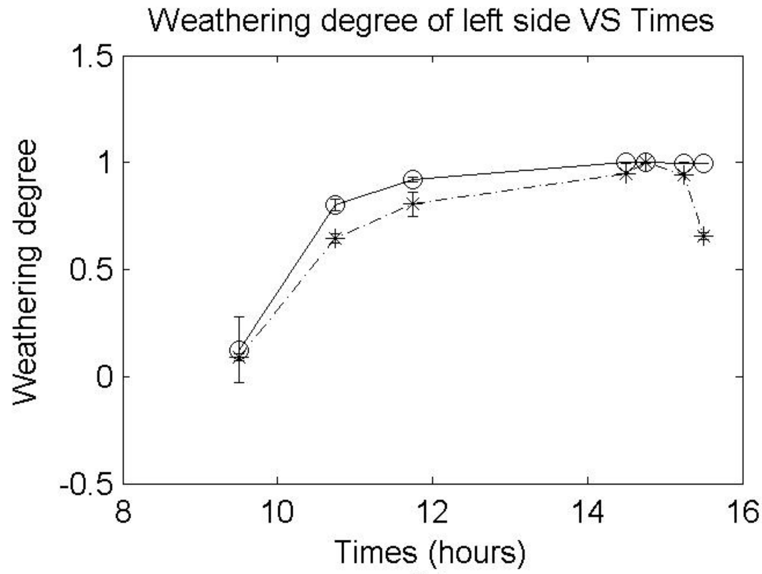
Table 3.4 The light intensity measured by lux meter

Side / Time	Left		Right		Front		Back	
	I_i	$\pm\Delta I_i$	I_i	$\pm\Delta I_i$	I_i	$\pm\Delta I_i$	I_i	$\pm\Delta I_i$
09.30.00	72.5	13.5	100	4	98	9	34.5	2.5
10.45.00	515	17	119	8	626.5	15.5	50	6
11.45.00	640.5	45.5	138.5	1.5	526	19	48	8
14.30.00	755	0	63	0	85	0	44	0
14.45.00	796 *	0	75	0	78	0	38	0
15.15.00	748	0	66	0	69	0	46	0
15.30.00	521.5	13.5	43	5	47.5	1.5	22.5	0.5

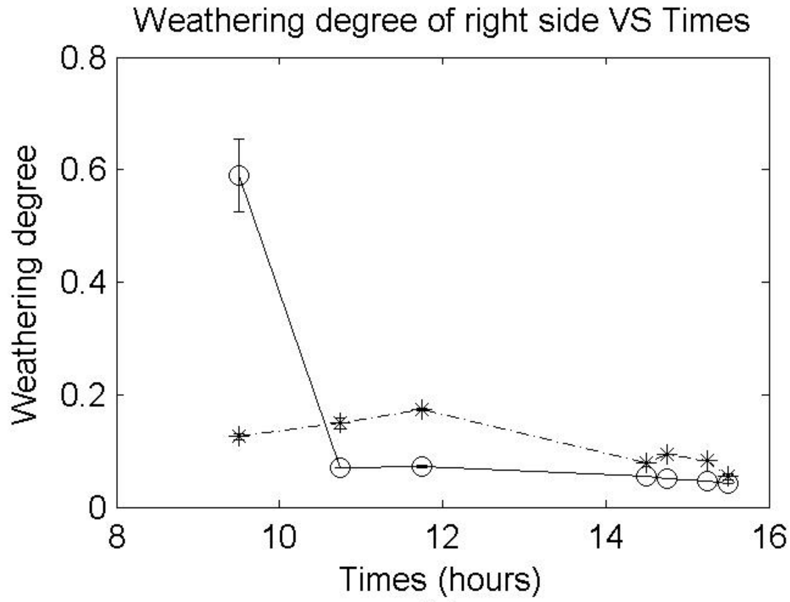
I_i = light intensity on each stone, measured by lux meter ; * = I_{max}

Table 3.5 The weathering degree (WD) calculated by lux meter data

Side / Time	Left		Right		Front		Back	
	WD_i	$\pm\Delta WD_i$	WD_i	$\pm\Delta WD_i$	WD_i	$\pm\Delta WD_i$	WD_i	$\pm\Delta WD_i$
09.30.00	0.091	0.017	0.126	0.005	0.123	0.011	0.043	0.003
10.45.00	0.647	0.021	0.149	0.010	0.787	0.019	0.063	0.008
11.45.00	0.805	0.057	0.174	0.002	0.661	0.024	0.060	0.010
14.30.00	0.948	0.000	0.079	0.000	0.107	0.000	0.055	0.000
14.45.00	1.000	0.000	0.094	0.000	0.098	0.000	0.048	0.000
15.15.00	0.940	0.000	0.083	0.000	0.087	0.000	0.058	0.000
15.30.00	0.655	0.017	0.054	0.006	0.060	0.002	0.028	0.001



(a)



(b)

Figure 3.17 The tendency comparison of weathering degree which estimated from spatial - temporal analysis (solid line) and measured by lux meter (dash line) : a. Left side b. Right side c. Front side and d. Back side

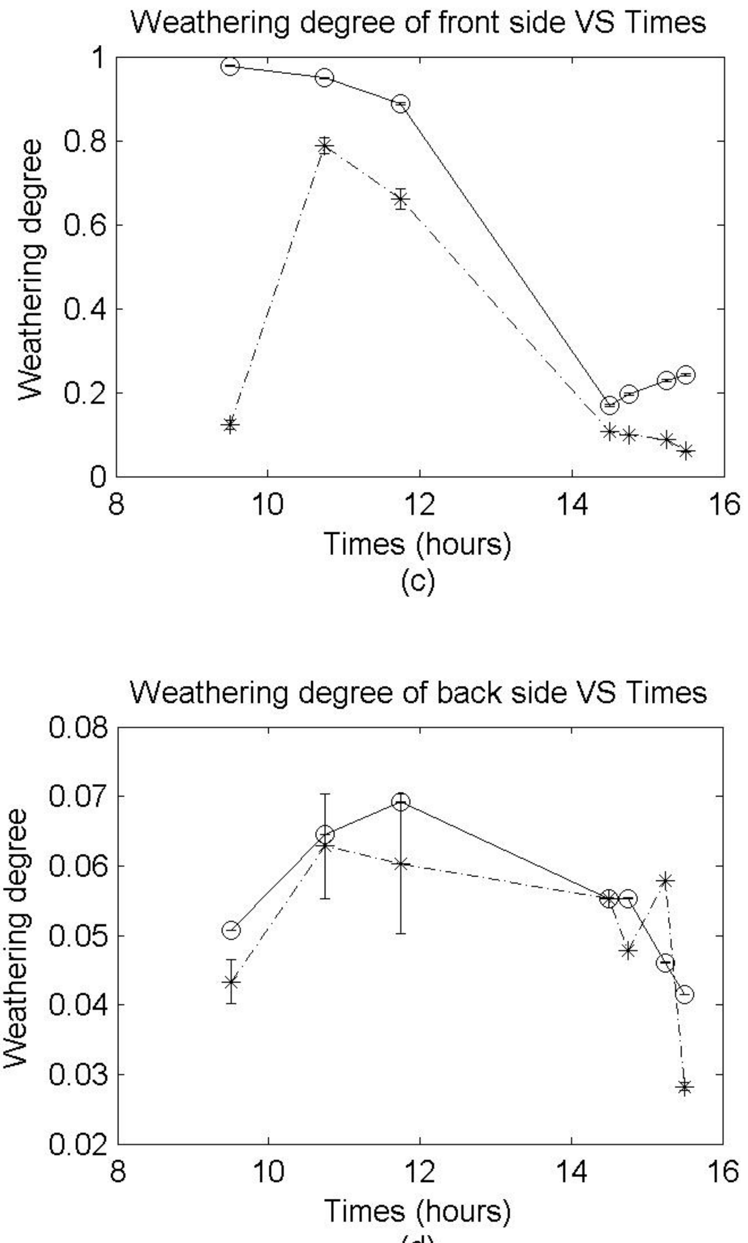


Figure 3.17 The tendency comparison of weathering degree which estimated from spatial - temporal analysis (solid line) and measured by lux meter (dash line) : a. Left side b. Right side c. Front side and d. Back side (Cont.)

Table 3.6 Mean values of weathering degree analyzed from spatial - temporal estimation ($\overline{WD_m}$) and measured by lux meter ($\overline{WD_l}$)

Side	spatial - temporal analysis		lux meter	
	$\overline{WD_m}$	Standard Error of $\overline{WD_m}$	$\overline{WD_l}$	Standard Error of $\overline{WD_l}$
Left	0.834	0.122	0.727	0.119
Right	0.132	0.076	0.108	0.016
Front	0.521	0.148	0.275	0.117
Back	0.055	0.004	0.051	0.005

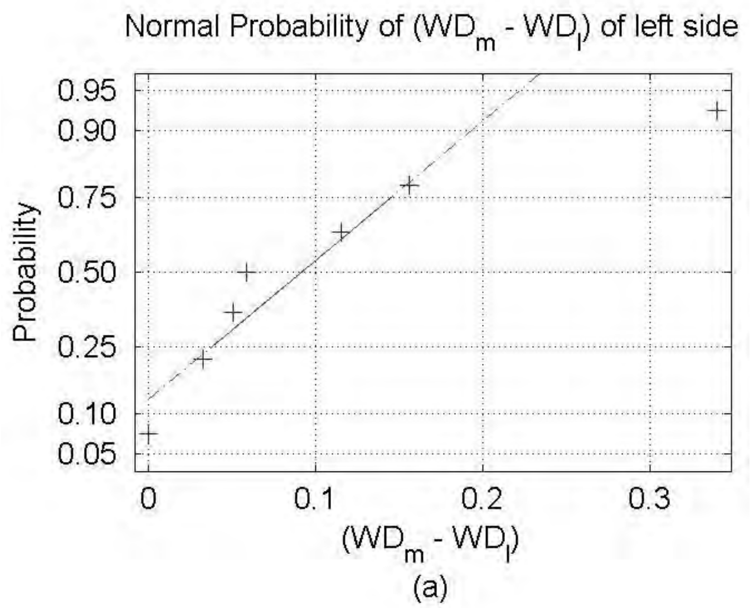
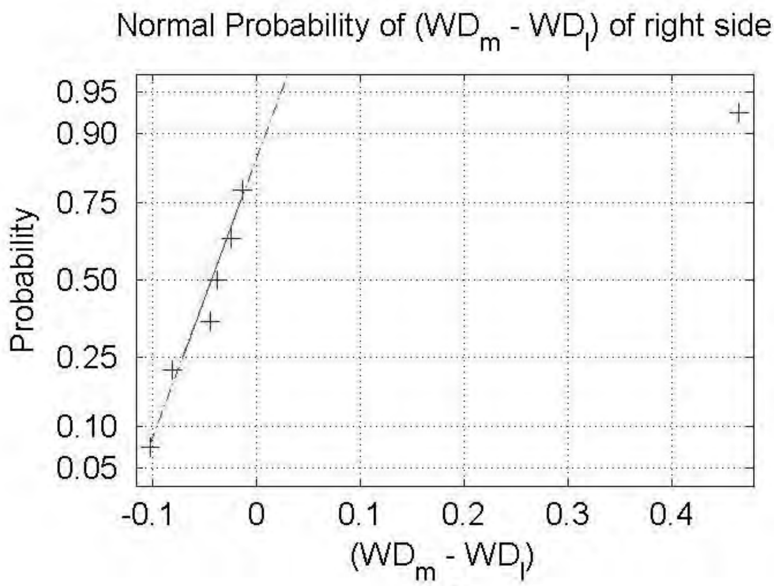
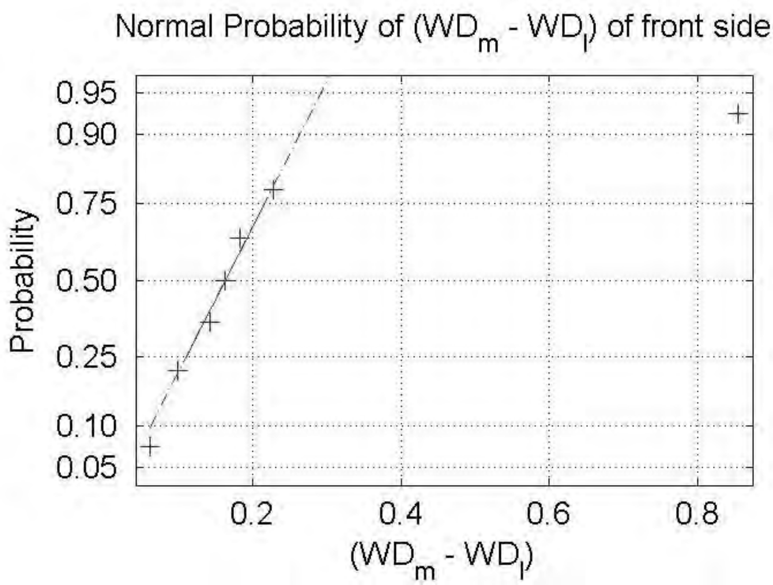


Figure 3.18 Normal Probability Plots of difference value ($WD_m - WD_l$) , WD_m and WD_l is weathering degree from spatial - temporal analysis and lux meter respectively. (difference values of each side scatters approximately follow straight, indicating approximate normal distributions) : a. Left side b. Right side c. Front side and d. Back side

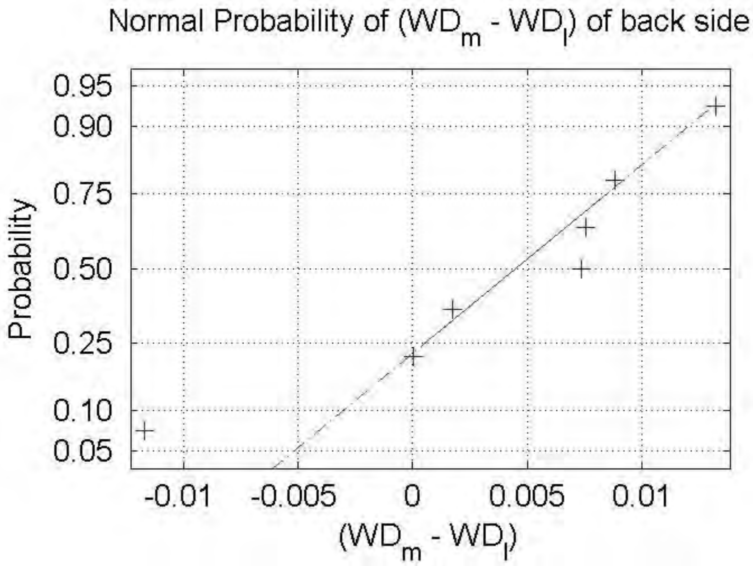


(b)



(c)

Figure 3.18 Normal Probability Plots of difference value $(WD_m - WD_l)$, WD_m and WD_l is weathering degree from spatial - temporal analysis and lux meter respectively. (difference values of each side scatters approximately follow straight, indicating approximate normal distributions) : a. Left side b. Right side c. Front side and d. Back side (Cont.)



(d)

Figure 3.18 Normal Probability Plots of difference value $(\mathrm{WD_m} - \mathrm{WD_l})$, $\mathrm{WD_m}$ and $\mathrm{WD_l}$ is weathering degree from spatial - temporal analysis and lux meter respectively. (difference values of each side scatters approximately follow straight, indicating approximate normal distributions) : a. Left side b. Right side c. Front side and d. Back side (Cont.)

Table 3.7 Result of paired T Test (null hypothesis is mean of difference value $(\mathrm{WD_m} - \mathrm{WD_l})$ equal to zero -- Note that mean of difference $\overline{\mathrm{WD_m} - \mathrm{WD_l}}$ equal to difference of mean $\overline{\mathrm{WD_m}} - \overline{\mathrm{WD_l}}$)

Side	$\overline{\mathrm{WD_m}}$	$\overline{\mathrm{WD_l}}$	T Test statics value
Left	0.834[a]	0.727[b]	t = 2.4749, df = 6, p = 0.0481
Right	0.132[a]	0.108[a]	t = 0.3177, df = 6, p = 0.7615
Front	0.521[a]	0.275[a]	t = 2.3885, df = 6, p = 0.0541
Back	0.055[a]	0.051[a]	t = 1.252, df = 6, p = 0.2572

The light intensity estimated by spatial - temporal analysis of each side of historical stone no 6 was the values reported in Table 3.2. The weathering degrees of stone no 6 were calculated by the equation from step 3.3.3. The weathering degree values were reported in Table 3.3 and Figure 3.18.

Finally, the model was validated by comparing the light intensity values which measured by lux meter. The light intensity values measured by lux meter, and weathering degree values calculated by lux meter data were reported in Table 3.4, 3.5 and Figure 3.18, respectively.

By statistic analysis as Table 3.7, the resulting of paired t-test presented that the WD_m were not significantly different from WD_l on the right, front and back sides, except the WD_m and WD_l on the left side which was significantly different due to its morphological surface was inconsistency.

3.4.4 Weathering degree of historical stone inscriptions by 3D image processing and spatial - temporal analysis

Total light intensity estimated by spatial - temporal analysis was reported in Table 3.8.

Table 3.8 The total light intensity ($I_{t,\ side}$) of historical stone inscriptions estimated by spatial - temporal analysis

Time	*Stone no 1*		*Stone no 2*		*Stone no 3*		*Stone no 4*	
	I_t	±Δ It	I_t	±Δ It	I_t	±Δ It	I_t	±Δ It
09.45	1807.57	35.87	2066.62	44.69	1303.84	27.10	1418.32	2.37
10.45	2051.27	5.52	2108.57	14.99	1922.41	43.01	1270.62	5.79
12.00	2047.28	7.44	2078.53	14.94	1946	12.26	944.08	15.93
14.30	1549.38	1.47	1612.7	8.63	1775.03	3.44	2248.7	10.52
15.00	1538.61	1.40	1605.36	9.30	1798.24	3.48	1182	11.97
15.30	1526.19	1.84	1586.59	10.45	1831.7	3.63	533.25	6.66
16.00	1493.58	1.81	1532.32	15.74	1820.88	4.19	531.05	0.81
16.30	1430.03	3.01	1401.76	26.54	1712.93	5.37	486.18	0.75
Time	*Stone no 5*		*Stone no 6*		*Stone no 7*		*Stone no 8*	
	I_t	±Δ It	I_t	±Δ It	I_t	±Δ It	I_t	±Δ It
09.45	1760.17	15.65	1412.25	36.22	1690.98	6.32	1606.94	4.37
10.45	1810.38	18.31	1303.23	11.41	1658.67	8.79	1616.86	2.52
12.00	2177.29 *	24.57	1254.64	16.53	1573.71	38.54	1901.88	21.29
14.30	1702.17	42.70	1109.6	3.67	1781.31	10.59	1955.63	8.75
15.00	1639.58	35.94	1139.65	3.91	1746.50	13.47	1875.68	17.38
15.30	1535.60	35.27	1179.06	4.25	1701.83	24.30	1673.59	2.90
16.00	1483.02	20.59	1191.38	4.37	1658.05	20.53	1580.83	21.51
16.30	1327.71	8.84	1270.32	8.10	1566.52	2.63	1175.74	8.39

Ii = Summation of grey scale of each side of the stone on 1/04/08, 1/09/08, /12/08 ;
***** = I_{max}

Table 3.9 The total light intensity ($I_{T, time}$) of historical stone inscriptions estimated by spatial - temporal analysis

Stone (no)	($I_{T, time}$)	$\pm\Delta I_{T, time}$
1	13443.91	37.32
2	13983.45	60.56
3	14111.03 *	53.09
4	7534.20	24.34
5	13435.92	77.74
6	9869.13	42.97
7	13377.57	53.99
8	13387.15	37.40

***** = I_{max}

The weathering degrees of the historical stone inscriptions were calculated and shown in table 3.10

Table 3.10 The weathering degree (WD) of historical stone inscriptions calculated by total light intensity ($I_{T, time}$) from spatial - temporal analysis

Stone (no)	WD_i	$\pm\Delta$ WDi
1	0.953	0.004
2	0.991	0.006
3	1.000	0.005
4	0.534	0.003
5	0.952	0.007
6	0.699	0.004
7	0.948	0.005
8	0.949	0.004

Based on the weathering degree values, the historical stone were divided to three groups,

Group 1 : Weathering degree ≈ 0.95 – 1.00

: Stone no 1, no 2, no 3, no 5, no 7, no 8

Group 2 : Weathering degree ≈ 0.70

: Stone no 6

Group 3 : Weathering degree ≈ 0.53

: Stone no 4

All results were illustrated as in Figure 3.20 and 3.21.

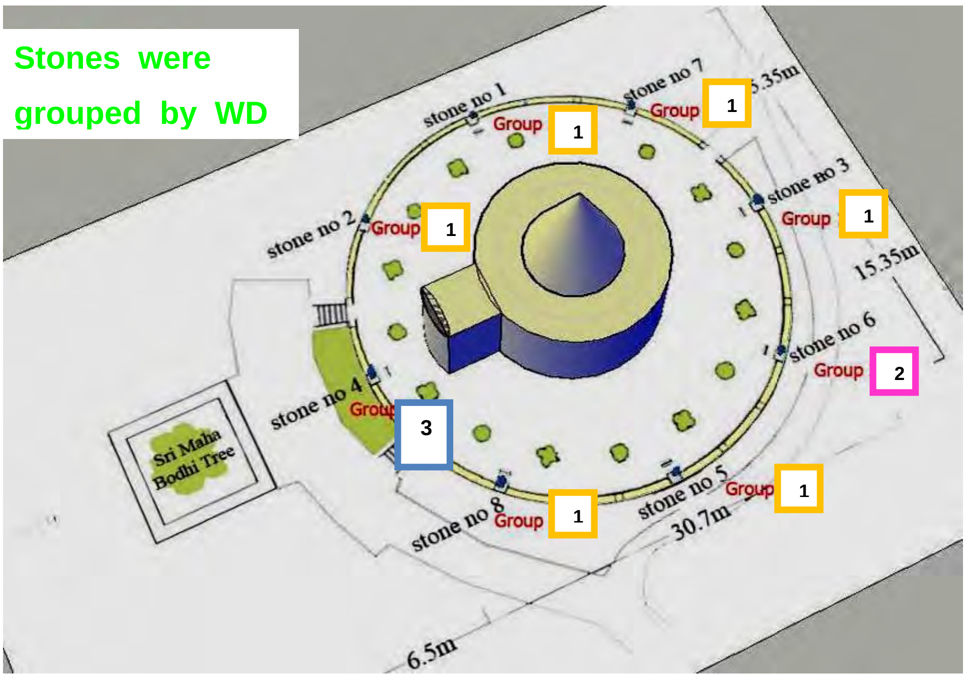


Figure 3.19 The historical stone inscriptions were grouped by the weathering degrees

Group 1 ; Weathering degree (WD) ≈ 0.95 – 1.00

Stone no 1 WD = 0.953 ± 0.004

WD_{1L} = 0.388±0.002 **WD_{1R} = 0.959±0.007** **WD_{1F} = 0.334±0.001** **WD_{1B} = 1±0.001**

Stone no 2 WD = 0.991 ± 0.006

WD_{2L} = 0.717±0.01 **WD_{2R} = 1±0.014** **WD_{2F} = 0.776±0.008** **WD_{2B} = 0422±0.004**

Figure 3.20 The weathering characterization of the historical stone inscriptions

Group 1 ; Weathering degree (WD) ≈ 0.95 - 1.00 (Cont.)

Stone no 3 WD = 1.00 ± 0.005

Left Right Front Back

WD_{3L} = 0.938±0.012 **WD_{3R} = 0.508±0.005** **WD_{3F} = 0.792±0.007** **WD_{3B} = 1±0.013**

Stone no 5 WD = 0.952 ± 0.007

Left Right Front Back

WD_{5L} = 0.913±0.017 **WD_{5R} = 0.511±0.011** **WD_{5F} = 0.892±0.015** **WD_{5B} = 1±0.024**

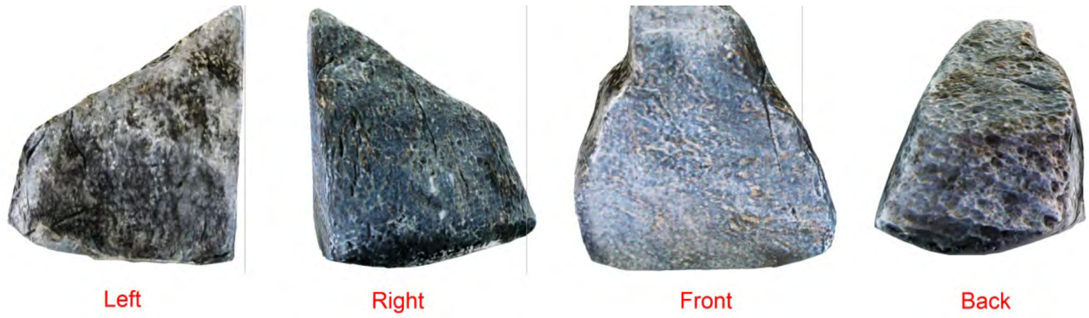
Figure 3.20 The weathering characterization of the historical stone inscriptions (Cont.)

Group 1 ; Weathering degree (WD) ≈ 0.95 – 1.00 (Cont.)

Stone no 7 WD = 0.948 ± 0.005

WD_{7L} = 0.393±0.009 **WD_{7R} = 0.659±0.005** **WD_{7F} = 0.542±0.000** **WD_{7B} = 1±0.000**

Stone no 8 WD = 0.949 ± 0.004



WD_{8L} = 0.834±0.006 **WD_{8R} = 0.553±0.004** **WD_{8F} = 0.889±0.007** **WD_{8B} = 1±0.007**

Figure 3.21 The weathering characterization of the historical stone inscriptions (Cont.)

Group 2 ; Weathering degree ≈ 0.70

Stone no 6 WD = 0.699 ± 0.004

WD_{6L} = 1±0.014 WD_{6R} = 0.274±0.005 WD_{6F} = 0.727±0.007 WD_{6B} = 0.5051±0.005

Group 3 ; Weathering degree ≈ 0.53

Stone no 4 WD = 0.534 ± 0.003

WD_{4L} = 0.2941±0.005 WD_{4R} = 0.700±0.005 WD_{4F} = 1±0.002 WD_{4B} = 0.633±0.005

Figure 3.20 The weathering characterization of the historical stone inscriptions (Cont.)

3.5 Discussion and Conclusion

The mineralogical compositions of the historical stone inscriptions analyzed by XRD technique indicated that they were limestones. Limestone are sedimentary rocks that made of mineral calcite ($CaCO_3$) which came from the beds of evaporated seas and lakes especially from sea animal shells (Payton, 1998). Its water absorption is approximately 1 - 2% and pore volume of the limestone is less than 6% (Chiraporn Aranyanark, 2001).

The results from this research supported the rock database (Figure 3.21) presented in geological database of Sichang island (Department of mineral resource, 2004).

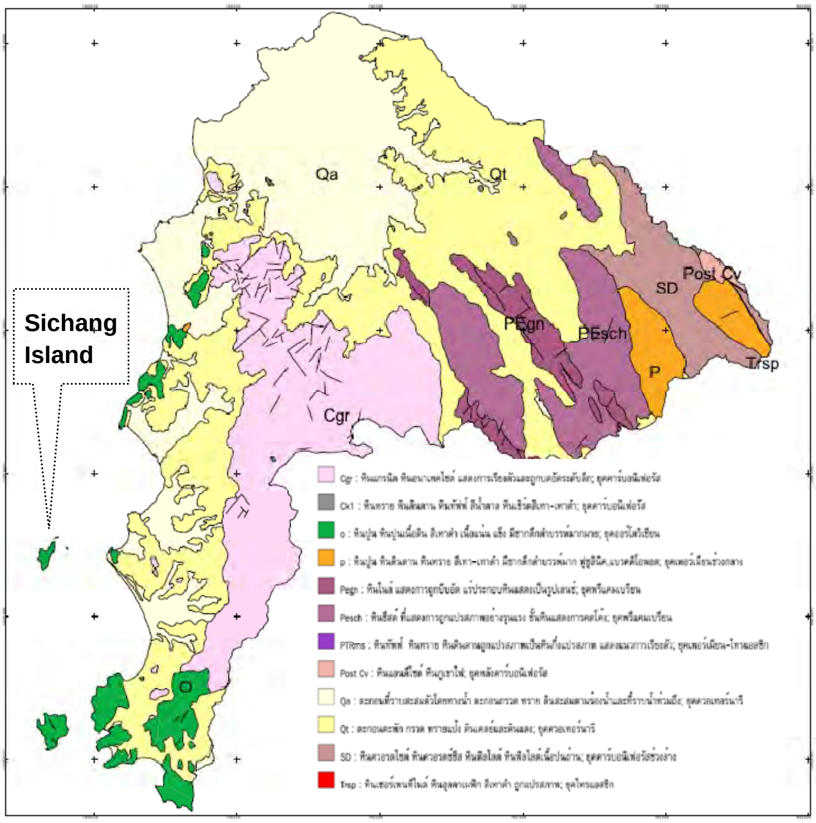


Figure 3.21 Chonburi rock database (Ministry of Natural Resources and Environmen, Department of mineral resource, 2004)

Correspondingly, the characteristic composition of historical stone inscription was identical in respects of the adjacent hill stone. The similarity of peak patterns from a diffractogram suggested that the two stone samples should be obtained from the same prior stone source.

The deteriorated cycle experiments were carried out in both rain water and sea water immersion. White stains or white crusts from sea water cycles was found. The white crust occurred when the stones were exposed to ambient surrounding. These results may be assumed that white crusts were salt crystals from sea water. Their process is known as efflorescence resulting from permeability of limestone (Tümer, 2003; Heritage Council of NSW, 2008). These permeability of stone is an important property in stone deterioration because it was associated with Kelvin law and thermodynamic as condensation - evaporation or wetting - drying cycles (Camuffo, 1995; Warke and Smith, 1998).

This research had two sections which focused on the cycle effect. Firstly, it was light cycles, and secondly, it was sea - water cycle. As a result of cycle experiment attempted to assess the effect of sea water and rain water affecting on the stones, both solution caused brown spots and also led to darkening color on the stone surfaces. These characteristics were the results of oxidation reactions (Dorsey et al., 1999) which were occurred by the interaction of oxygen molecules from atmosphere, water and mineral constituents of stones as describe in equation 3.4 (Shreie, 1978).

$$
\begin{array}{lcl}
Fe + H_2O & \longleftrightarrow & Fe(OH) + H^+ \\
Fe(OH)^- & \longleftrightarrow & Fe(OH) + e^- \\
Fe(OH) & \longleftrightarrow & Fe^{2+} + OH^- + e^-
\end{array}
\quad \text{-------} \quad 3.4
$$

Iron (Fe) interacted with oxygen to form a hydrated iron oxide. This reaction appeared on the stone that comprised of iron (Chiraporn Aranyanark, 2001). Occasionally, it was found that ferous (Fe^{2+}) could be oxidized to be ferric (Fe^{3+}) or known as red iron oxide. The reason to explain brown spots thoroughly on the stone samples may be because of iron oxidation. Additionally, the stone samples treated with sea water cycles were distinct color changing more than the rain water cycles.

Calcite ($CaCO_3$), actinolite [$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$], silicon (Si), sodium calcium silicate (Na_2CaSiO_4) and albite, calcian, orderd [(Na,Ca) Al(Si, Al)$_3$O$_8$ were found in stone samples which treated with sea water cycles. While the stone samples which treated with rain water were found only calcite, actinolite and calcium silicate.

Silicon, aluminum and sodium are the minerals of sea water (Paterson, M.P. and Scorer, 1975; Suwaj Thanyaros, 2007; National Science Foundation, n.d.) so that they could react with calcite, actinolite and calcium silicate to form sodium calcium silicate and albite.

Albite is a plagioclase feldspar mineral. It is the sodium and member of the plagioclase solid solution series. Its color is usually pure white. Hence, the darkening appearance would be expected to be caused by silica compounds which is bluish - tinged.

Diffractogram of rain cycles treatment indicated that mineral compounds of the treated stones were similar to untreated stone samples, but just its appearance that was changed, its color rather more dakening than the raw stones.

Besides, the overviews for salt effects on the stones concluded that soluble salts were being the most important degradation products (Pérez et al., 2004). Salt crystallization might cause a further weakening of the mineral lattice (Warscheid and Braams, 2001) due to the durability of the stones were closely related to their chemical and mineralogical composition (Zedef et al., 2005). These phenomena were admitted to explain the loss of silicate crystals (Figure 3.22).

The study on technical development to estimate sunlight intensity on historical stone surface, the trend lines of sunlight intensity measured from in situ were rather different from the trend lines estimated from spatial analysis. At this point, it could be explained by physical properties of light. Generally, the scattering and diffraction of sunlight are affected from aerosol particulates on sunrise and sunset, so the measurement of sunlight intensity values in this study in morning and afternoon by lux meter were lower than the estimated values by spatial analysis.

However, from this research, after calibrating and validating the data, the spatial model technique could be used to predict sunlight intensity during a day instead of the measurement using Lux meter. The developed technique would be more reliable than the old - fashioned technique. The advantages of this technique are faster and more precise (Vatan and Arun, 2005). The data could be collected with low cost. However, this study concentrated only on sunlight, not considered to the other meteorological factors such as wind and cloud including biotic factors such as tree shading. So, this technique needs to be developed for more further accuracy.

In order to classify the weathering degree of the historical stone inscriptions, the results were divided the weathering degree into 3 groups (Figure 3.20). By the weathering degree compared among each side of a historical stone (left, right, front and back), the results were related to sun orbital. The more time of the side exposed to sunlight, the more value of weathering degree was found. These results were related to the represented of the study which was reported that limestones weathering rate depends on the surface angle to the horizon (Winkler, 1987).

The stone no 1, 2, 3, 5, 7 and 8 were in the most weathering degree group (group 1 : ≈ 0.95 - 1), whereas the weathering degree values were lower at the stone no 6 (group 2 : ≈ 0.70) and the stone no 4 (group 3 : ≈ 0.53), respectively. Most of the stone inscriptions around Aussadangkhanimit Temple obtained sunlight directly about 10 hrs a day, except the stone no 6 and 4. The stone no 6, in the afternoon, was partly protected from direct contact with sunlight by the shadow of Aussadangkhanimit Temple. Likewise, the stone no 4 was covered with the shade of Sri Maha Po Tree in morning and the shadow of Aussadangkhanimit Temple in the afternoon.

Supporting the analysis result by the old photographs was reported that stone no 4 and stone no 6 ever had the trees behind it and the shadow of that tree protected that stone inscription from the light intensity, thus the weathering degree of the stone inscription no 6 and 4 (Fig 3.22) were divided into weathering degree group 2 and 3 respectively.

Figure 3.22 Aussadangkhanimit Temple at the past times (Por Mahakhan, 1997)

During the observation of rain water evaporation from the stone inscriptions (Figure 3.22), the water evaporation began at the center of the stones. Interestingly, the stone surface was fading at the evaporized zone much more than the other areas. This phenomenon may be referred to immediately thermal changing affecting on expanding - shrinking of the stone material (Chiraporn Aranyanark, 2001) also, correspond to the stone weathering phases which identified as Figure 3.24

Figure 3.23 The evaporation phenomenon of the historical stone inscriptions

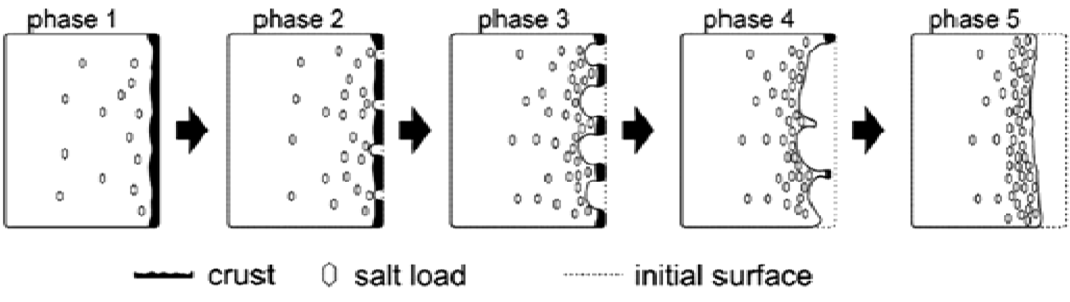


Figure 3.24 The schematic of limestone damage (Rothert et al., 2007)

CHAPTER IV

THE EFFECT OF ENVIRONMENTAL FACTORS ON LIME PLASTER DETERIORATION

4.1 Introduction

Lime plaster is the mixture of calcium hydroxide, sand or other inert filler materials. It has been used for historic buildings for over 5,000 years (SustainableBuild, 2009) because of an important property which was highly workable (Hanley and Pavia, 2008). Presently, the lime plasters have been destroying. The destructibility of the lime plaster was reported that concerning the environment. The environmental conditions played an important role in determining the occurrence of the decay (Lubelli et al., 2006) especially the maritime climate (Australian Goverment, 2007). Lime plaster deterioration was related to salt source from marine spray deposition and water capillary rising (Sabbioni et al., 2002), and wind also was believed to trigger alveolar weathering (Cardell et al., 2003). As the mentioned results of the research, the assumption that would be conducted to this study.

4.2 Objectives

The experiment was conducted to investigate the lime plaster surface deterioration at Apirom residence, Phongsri residence, Wattana residence and Aussadangkhanimit Temple. Moreover, this study was also undertaken to find out the relation of the physical factors affecting on the deterioration at Apirom residence by using integrated methods as in situ measurement, image processing and geometric calculation technique.

4.3 Materials and methods

4.3.1 The relation of humidity and light intensity affecting on the deterioration of lime plaster surface

The wall surfaces outside Apirom residences were selected to study the lime plaster deterioration. It was chosen because of its obvious deterioration. The walls were expected to estimate incident light intensity using application program conveniently .

Three steps of the study were carried out as followed in Figure 4.1.

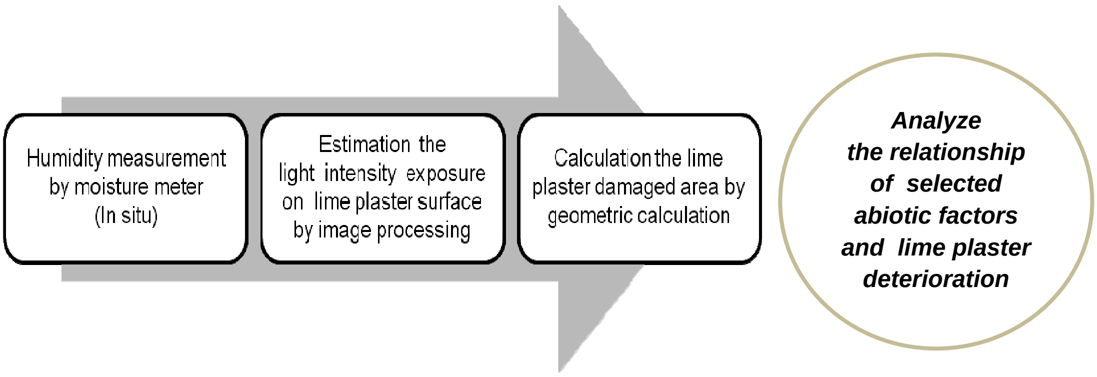
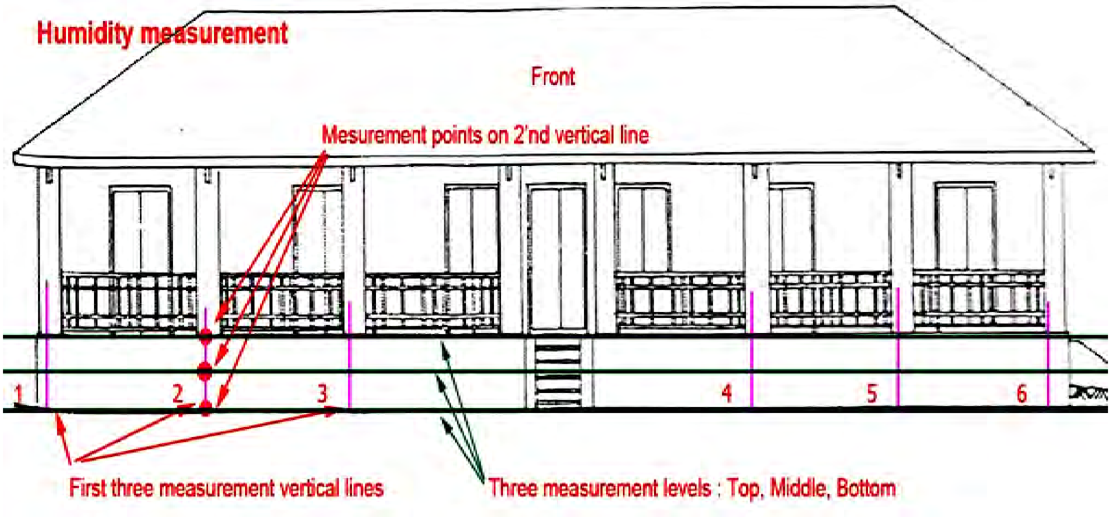


Figure 4.1 Methodology procedure

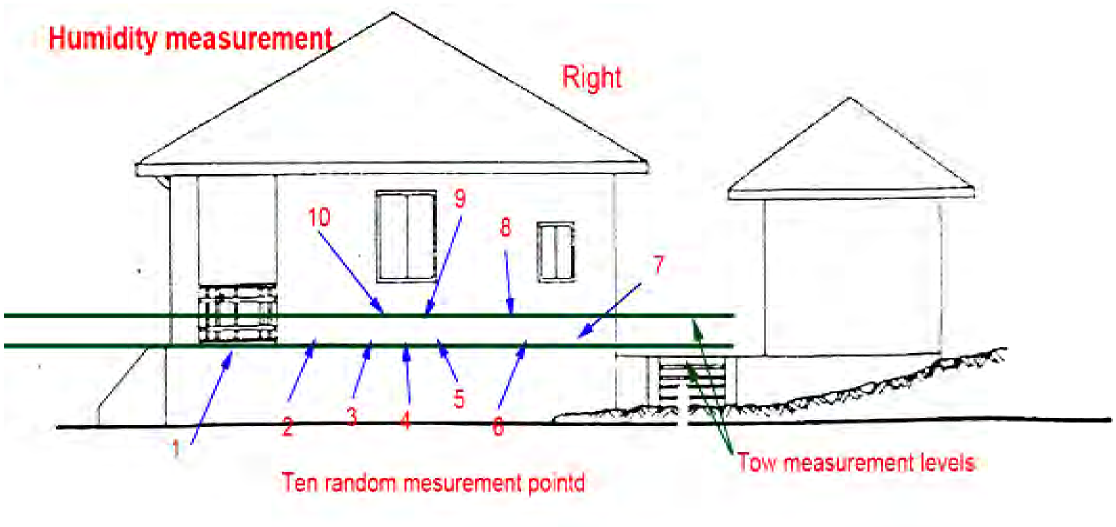
Firstly, the humidity measurement was undertaken on each side using moisture meter model CEM DT-128. Measurement points were marked on the plaster of the walls outside the building of Apirom residence (Figure 4.2). For the back and right sides of the building, similar pattern of measurement points were also marked. After that, all of humidity values of each side were calculated for mean values.

Henceforth, the light intensity was estimated using spatial temporal analysis. The method was mentioned as in Chapter 3. The Apirom residence was mapped. Then, light intensity on each of surface sides of the Apirom residence was rendered. The data on selected three days (Apirl 1st, September 1st, and December 1st, 2008) were put into application software. Each day was estimated for 3 times as followed : 10.00 am. 12.00 am and 2.00 pm.



a. Front

Figure 4.2 Measurement points on lime plaster surface outside the walls at Apirom residence : a. Front side b. Left side



b. Left side

Figure 4.2 Measurement points on lime plaster surface at Apirom residence : a. Front side b. Left side (Cont.)

Damaged areas of lime plaster surface on front, back, right and left sides of the building were calculated. Then, the value of each side was summarized to represent as the damaged area of that side and was used to study the relation of lime plaster deterioration causing by abiotic factors later. The geometrical application program, On site Photo, was used to process the data.

After the estimation of light intensity, the measurement of humidity and the calculation of lime plaster damaged area were finished. Eventually, the relation of humidity and light intensity was deliberated about the effect on lime plaster surface.

4.3.2 Abiotic factors affecting on deteriorated characterization of lime plaster

The experimental study has been carried out by investigating and visual analyzing on lime plaster surface, the deteriorated characterization of the investigated areas was sorted out.

Besides, those damaged lime plaster areas were analyzed for saltness as chloride salt, sulfate salt and nitrate salt which might be deposited on those surfaces. This analytical step was began with using cotton sheets saturated with deionized water 2 ml to wipe at lime plaster damaged areas. Then, each of the cotton sheet was squeezed the absorbed solution out into three test tubes, 1 ml per a test tube. Later, the solutions in the test tubes were checked for salinity.

The first test tube was tested for chloride salts by adding two drops of diluted nitric acid (HNO_3) to adjust acidity of the sample solution. Then, five drops of 5% silver nitrate ($AgNO_3$) were added into the test tube. If white precipitation was observed, it meaned that the solution was contaminated by chloride salt. The second test tube was prepared to test for sulfate salts by adding two drops of 5% Barium chloride ($BaCl_2$) into the test tube. After that, observed white precipitation indicated the positive result.

The last test tube was tested as the method that called 'brown ring test'. The beginning of the test was carried out by adding concentrated sulpuric acid (H_2SO_4) to adjust the acidity of the sample solution. Next, the solution was added with five drops of saturated solution of ferrous sulfate ($FeSO_4$) and mixed gently before inclining the test tube at 45 ^{o} angle. Again, the solution was added with five drops of concentrated H_2SO_4, then rolled down the side of the test tube slowly. Colloidal iron (II) sulfate solution or brown ring was formed near the bottom of the test tube to show the positive result of nitrate salts. Results of this experiment were ranked by the amount of precipitation or the distinguishable brown ring. Moreover, the sample solutions were also tested the salinity value using Salt meter model DSG-10 for 3 time and then those salinity values were averaged, afterwards.

4.4 Results

4.4.1 The relation of humidity and light intensity affecting on the deterioration of lime plaster surface

For clear results, this experimental research used aerial photographs from Google Earth to identify study sites. Apirom residence location was shown in Figure 4.3 and 4.4.

Figure 4.3 Apirom residence location

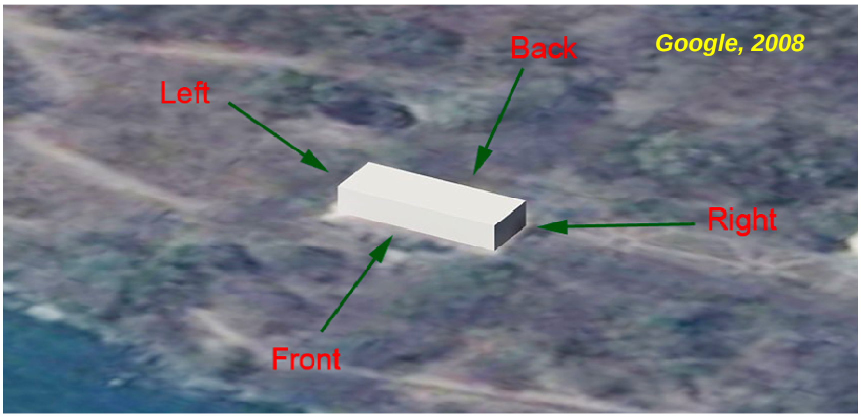


Figure 4.4 Apirom simple block model

Overall data, the humidity values measured by apparatus and light intensity values estimated by image processing method were combined to analyze their effect on lime plaster. The humidity and light intensity values were described in Table 4.1, 4.2, 4.3 and 4.4 as followed.

Table 4.1 Humidity measuring values at the front side of Apirom residence

Humidity (% RH) ± 0.1 *			
Level / Vertical lines	Top	Middle	Bottom
1	21.6	30.4	15.1
2	9.4	24.2	39.1
3	10.7	18.1	27.2
4	8.9	11.4	11.6
5	9.1	44.5	14.2
6	8.1	42.1	24.5

Mean = 21 S.D .= 12 **;** ***** Measured on 16 November, 2008

Table 4.2 Humidity measuring values at the back side of Apirom residence

Humidity (% RH) ± 0.1 *			
Level / Vertical lines	Top	Middle	Bottom
1	11.7	23.4	8.0
2	13.2	13.6	8.5
3	18.3	15.3	10.5
4	32.7	17.7	10.2
5	15.6	23.8	18.9
6	13.4	8.5	18.7

Mean = 16 S.D .= 7 **;** ***** Measured on 16 November, 2008

Table 4.3 Humidity measuring values at the right side of Apirom residence

Measuring point	**Himidity (% RH) ± 1% ***
1	13.8
2	46.5
3	31.4
4	29.0
5	57.0
6	32.5
7	28.1
8	50.8
9	42.5
10	86.5

Mean = 41.8 S.D .= 20.2 ; ***** Measured on 16 November, 2008

Table 4.4 Humidity measuring values at the left side of Apirom residence

Measuring point	**Himidity (% RH) ± 1%**
1	11.3
2	12.0
3	13.5
4	12.9
5	11.7
6	11.2
7	8.1
8	8.0
9	8.1
10	8.1

Mean = 10.5 S.D .= 2.2

The light intensity was also analyzed by image processing or using greyscale photographic data as in Chapter 3. The greyscale photographic data at each time were used to calculate the average light intensity.

The results of light intensity estimated by image processing were presented in Figure 4.5

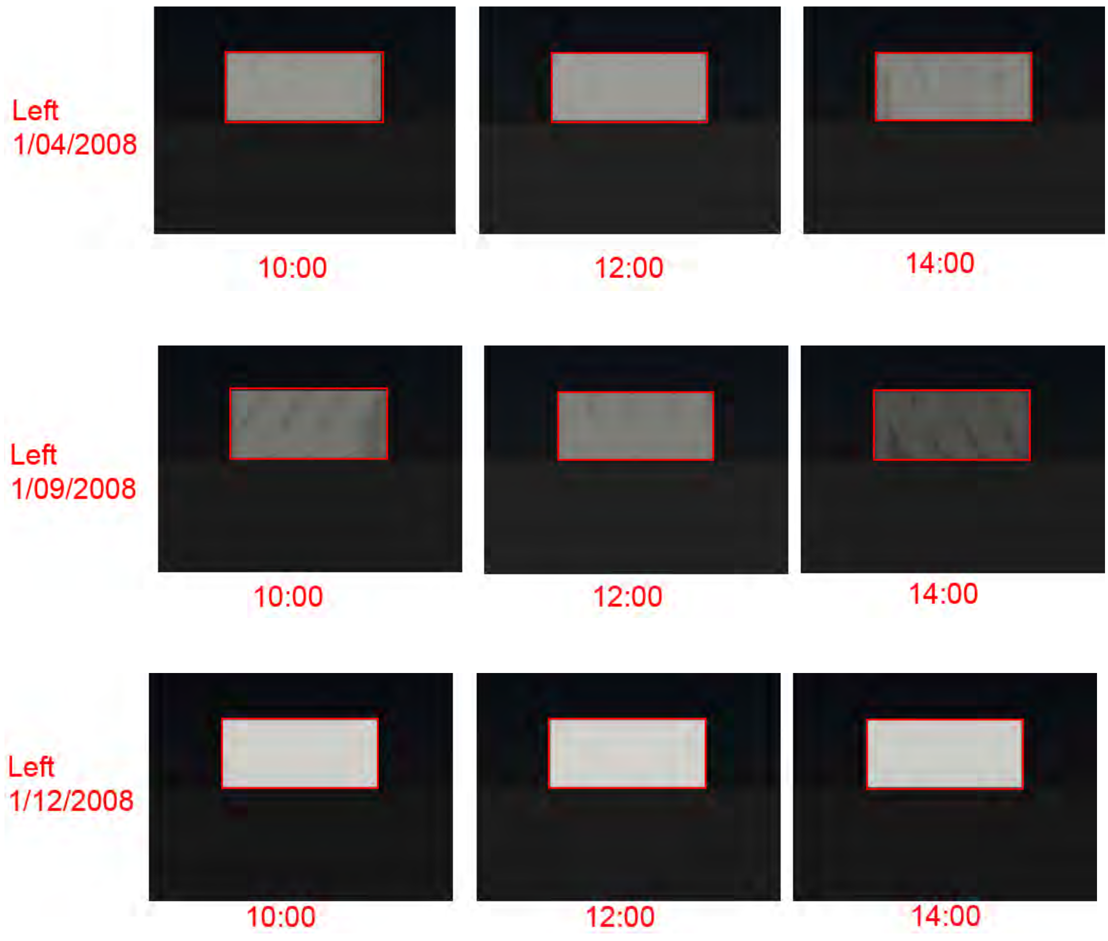


Figure 4.5 Light intensity data estimated by image processing

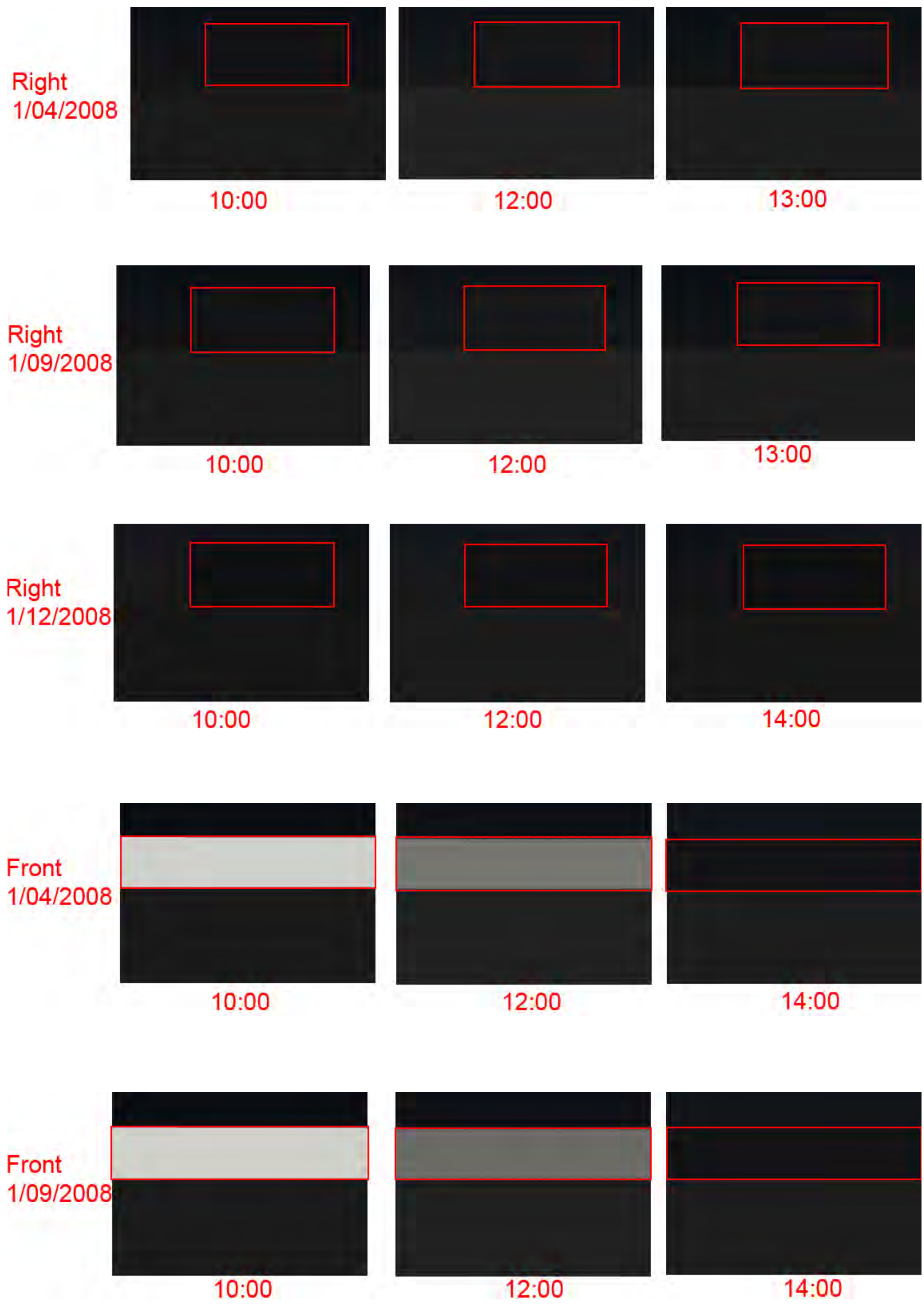


Figure 4.5 Light intensity data estimated by image processing (Cont.)

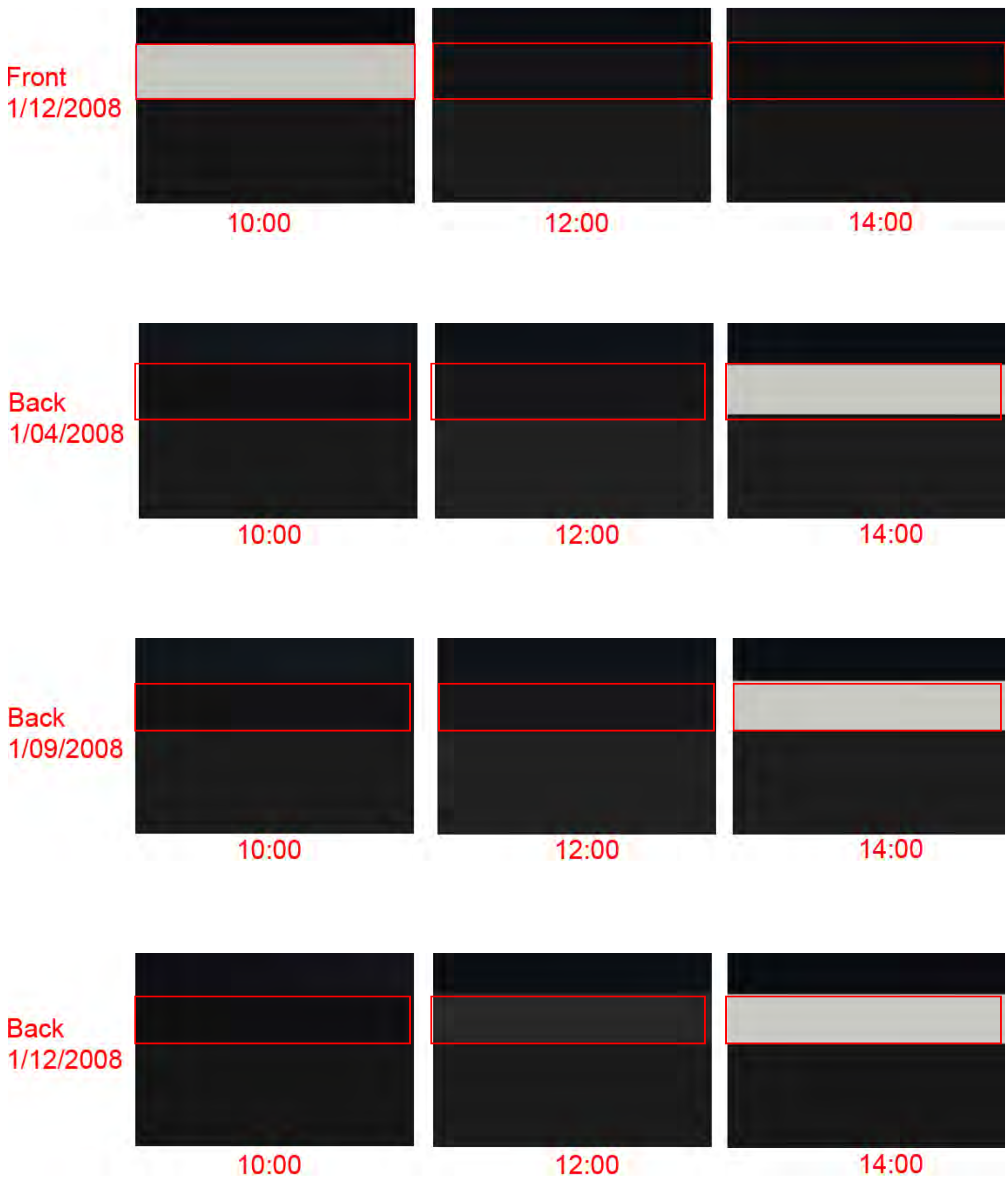


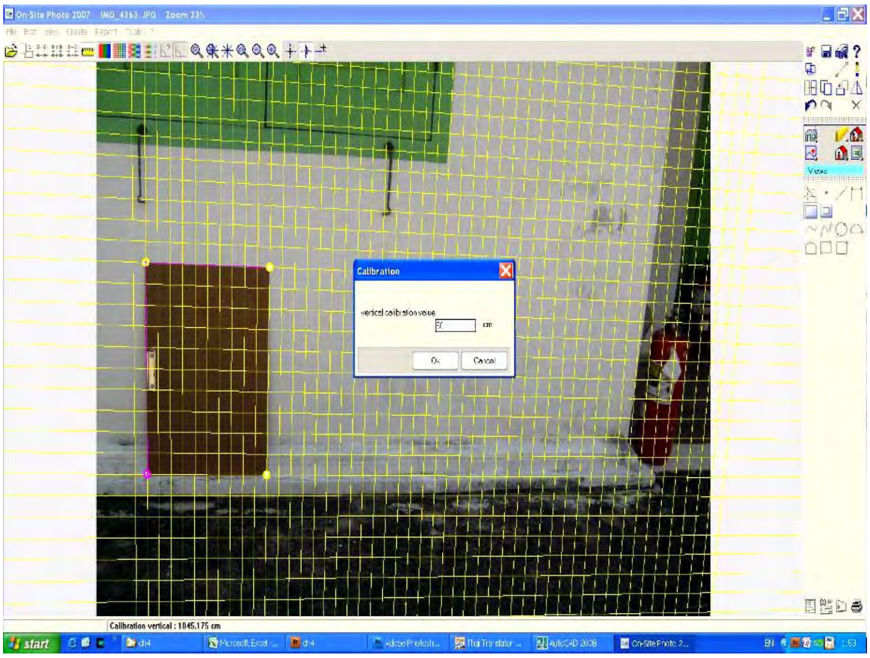
Figure 4.5 Light intensity data estimated by image processing (Cont.)

The light intensity results at 10.00 am. 12.00 am and 2.00 pm. were averaged. These averaged values were summarized to represent as the light intensity affecting on that side of the lime plaster surface. The results were shown in Table 4.5.

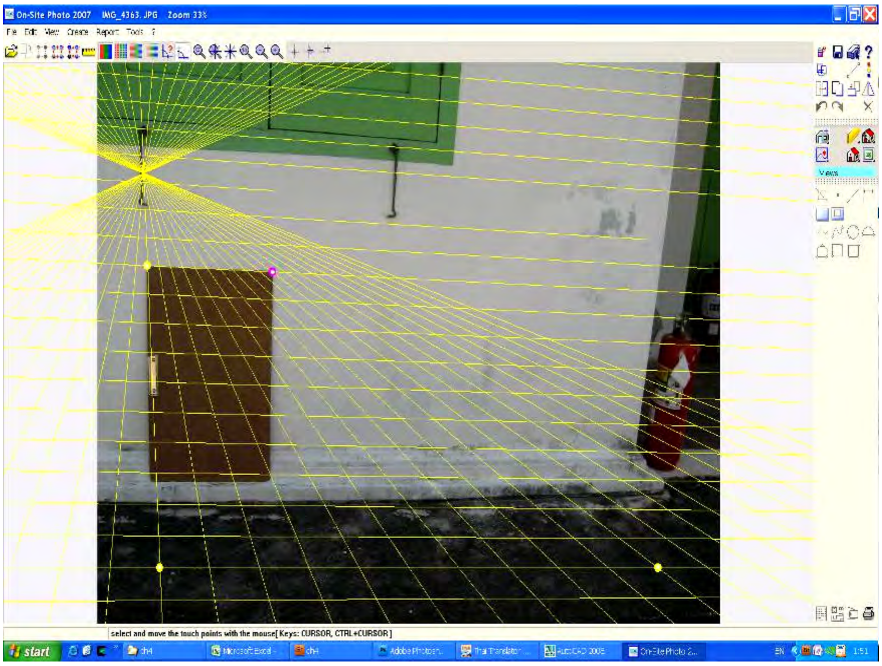
Table 4.5 Light intensity value estimated by image processing

Light intensity estimating value	
Left side	1361 ± 1
Right side	178 ± 4
Front side	912 ± 2
Back side	747 ± 3

The lime plaster damaged areas calculated by application software : On site Photo was shown in Figure 4.6. It was found that On site Photo program could calculate damaged area more conveniently than in situ measuring such as high accuracy and ability to analyze the data in the laboratory. However, the program had some limitations such as unreliability on taking the photographs with calibration plates and unsuitability for small area or hard observed area.

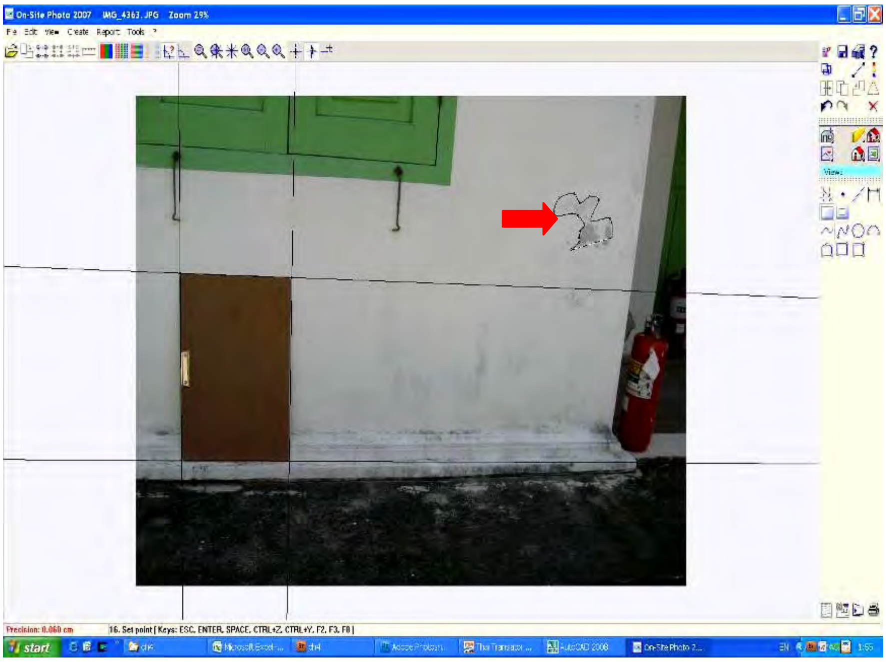


a. Co - ordinate system arrangement

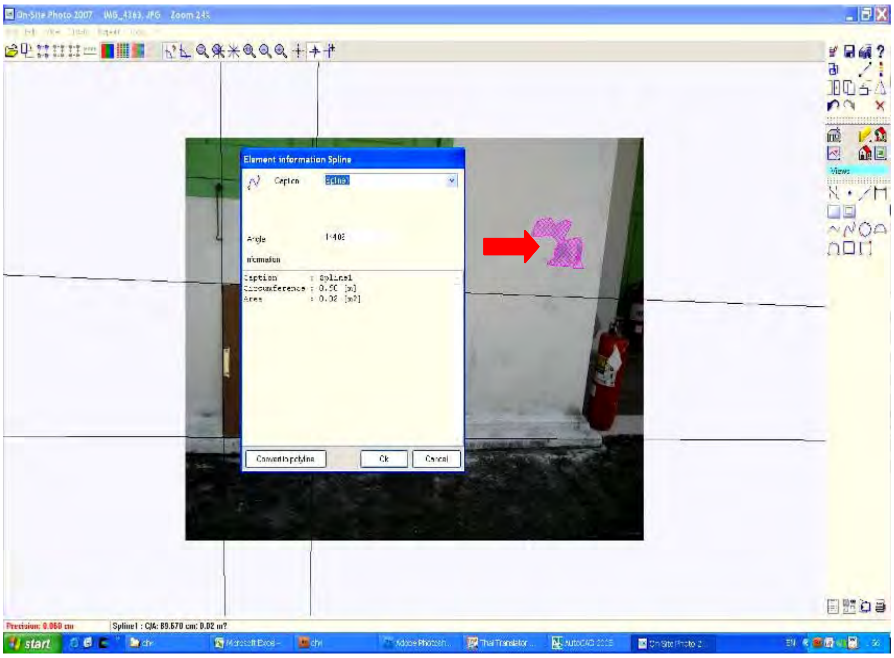


b. Co - ordinate scaling correction

Figure 4.6 Process of the geometrical calculation to calculate damaged areas by Onsite Photo : a. Co - ordinate system arrangement b. Co - ordinate scaling correction c. Drawing of damaged area and d. Calculation of damaged area



b. Co - ordinate scaling correction



d. Calculation of damaged areas

Figure 4.6 Process of the geometrical calculation to calculate damaged areas by Onsite Photo : a. Co - ordinate system arrangement b. Co - ordinate scaling correction c. Drawing of damaged area and d. Calculation of damaged area (Cont.)

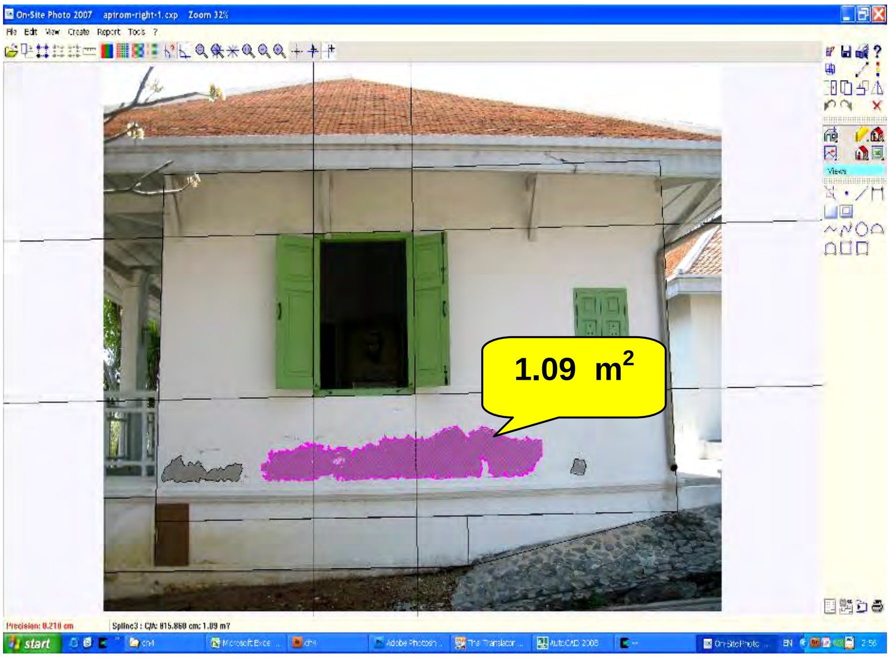


Figure 4.7 The example of damaged area analyzed by image processing

All damaged areas of each side which already had been summarized were reported as in Table 4.6.

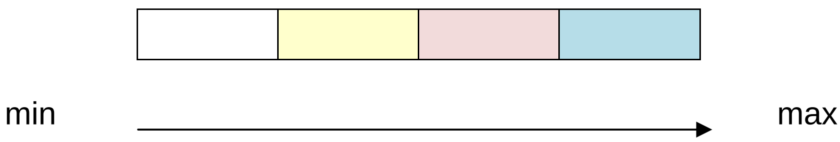
Table 4.6 Damaged area of lime plaster surface*

Damaged area (m^2)	
Left side	0.00
Right side	1.24 ± 0.2
Front side	0.65 ± 0.1
Back side	0.22 ± 0.03

* estimated only obviously damaged area

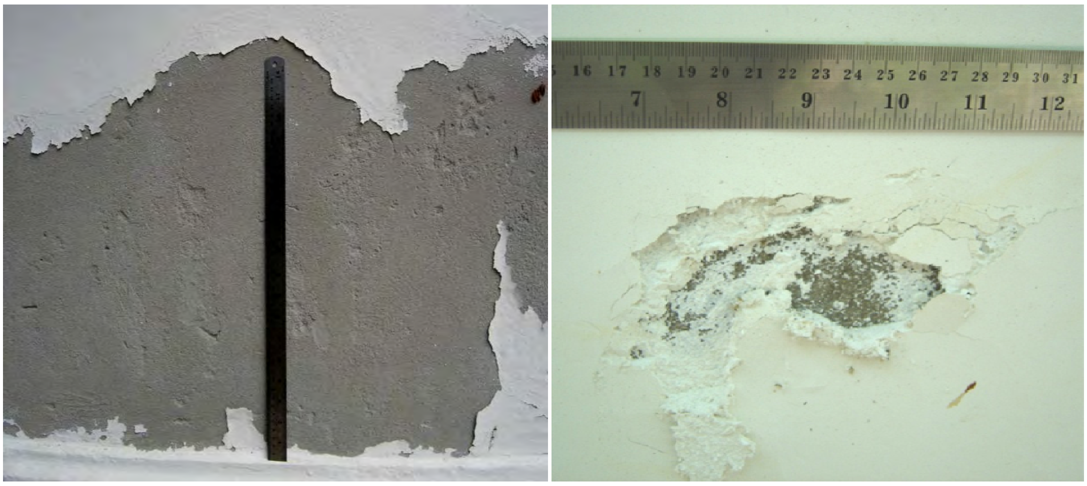
Table 4.7 Summary of abiotic factors values and lime plaster damaged areas on each side

Side \ Parameter	Lime plaster damaged area ; m^2	Humidity values (Mean) ; % RH	Light intensity Values
Left side	0.00	10.5 ± 2.2	1361 ± 1
Right side	1.24 ± 0.2	41.8 ± 20.2	178 ± 4
Front side	0.65 ± 0.1	21 ± 12	912 ± 2
Back side	0.22 ± 0.03	16 ± 7	747 ± 3



4.4.2 Abiotic factors affecting on deteriorated characterization of lime plaster

Deteriorated lime plaster areas were investigated and classified mainly deteriorated characterization as two groups. The first was lime plaster peeling and the second was lime plaster blast off. Their characterization were displayed in Figure 4.8.



a. lime plaster peeling   b. lime plaster blast off

Figure 4.8 Lime plaster deteriorated characterization : a. lime plaster peeling and b. lime plaster blast off

Based on salt attack hypothesis, the salinity measurement was undertaken by focused on only the damaged areas and their results were shown in Table 4.8.

Table 4.8 Salt test data and salinity values

Sampling site no	Damaged characterization		Salt test			Salinity (ppt)
	peeling	blast off	Chloride	Sulfate	Nitrate	
Wattana 1	✓	-	++++	+	-	7.3
o main room o downstairs o inner wall o left side o direction : WS o ~1.32 m. from ground						
Wattana 2	✓	✓	++++	+	+	11.0
o main room o downstairs o inner wall o back side o direction : WN o ~1.10 m. from ground						
Wattana 3	✓	✓	++++	+	+	16.0
o small room o downstairs o inner wall o back side o direction : WN o 1.7 m. from ground						

Table 4.8 Salt test data and salinity values (Cont.)

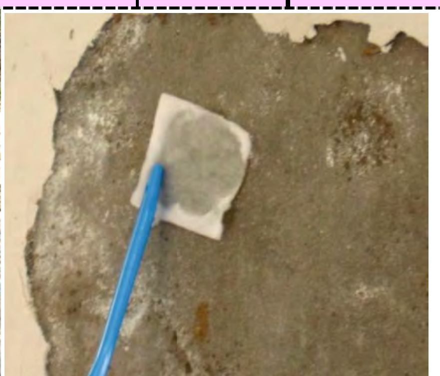
Sampling site no	Damaged characterization		Salt test			Salinity (ppt)
	peeling	blast off	Chloride	Sulfate	Nitrate	
Wattana 4	✓	-	+	-	+	3.6
o downstairs o outer wall o front o direction : ES o 1.05 m. from ground	 					
Phongsri 1	✓	✓	+++	+	+	11.0
o pillar surface o back side o direction : W o ~2.1 m. from ground	 					
Phongsri 2	✓	✓	+++	+	+	7.7
o edge o doorway wall o direction : WWS o ~1.2 m. from ground	 					

Table 4.8 Salt test data and salinity values (Cont.)

Sampling site no	Damaged characterization		Salt test			Salinity (ppt)
	peeling	blast off	Chloride	Sulfate	Nitrate	
Phongsri 3	✓	✓	++++	+	+	12.3
o pillar surface o back side o direction : W o 1.36 m. from ground						
Phongsri 4	✓	✓	+++	+	+	14.5
o pillar surface o back side o direction : W o ~2.10 m. from ground						
Phongsri 5	✓	✓	+++	+	++	11.6
o pillar surface o back side o direction : W o ~1.4 m. from ground						

Table 4.8 Salt test data and salinity values (Cont.)

Sampling site no	Damaged characterization		Salt test			Salinity (ppt)
	peeling	blast off	Chloride	Sulfate	Nitrate	
Apirom 1	✓	-	+++	+	-	9.0
o pillar surface o front o direction : E o ~1.2 m. from ground						
Apirom 2	✓	-	+++	+	+	6.1
o pillar surface o front o direction : E o ~1.2 m. from ground						
Apirom 3	✓	-	++++		+	5.6
o outer wall o right side o direction : N o ~1.2 m. from ground						

Table 4.8 Salt test data and salinity values (Cont.)

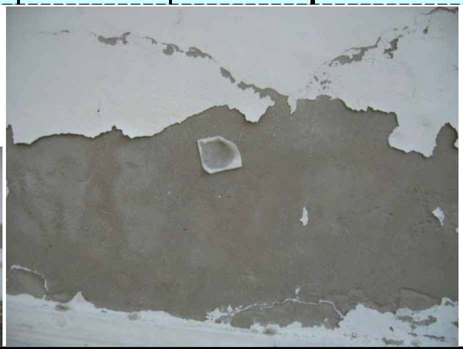
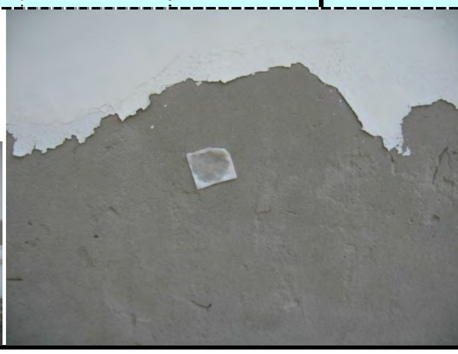
Sampling site no	Damaged characterization		Salt test			Salinity (ppt)
	peeling	blast off	Chloride	Sulfate	Nitrate	
Apirom 4	✓	-	+++	+	-	5.0
o outer wall o right side o direction : N o ~1.2 m. from ground						
Apirom 5	✓	-	+++	+	+	4.2
o outer wall o right side o direction : N o ~1.2 m. from ground						
Apirom 6	✓	-	++++	+	+	3.4
o outer wall o right side o direction : N o ~1.2 m. from ground						

Table 4.8 Salt test data and salinity values (Cont.)

Sampling site no	Damaged characterization		Salt test			Salinity (ppt)
	peeling	blast off	Chloride	Sulfate	Nitrate	
Apirom 7	✓	-	+++	+	+	0.5
o outer wall o left side o direction : S o ~1.62 m. from ground						
Apirom 8	✓	-	+++	+	+	0.23
o outer wall o left side o direction : S o ~1.62 m. from ground o						
Apirom 9	✓	-	+++	+	+	0.43
o outer wall o back side o direction : S o ~1.2 m. from rock basemant						

Table 4.8 Salt test data and salinity values (Cont.)

Sampling site no	Damaged characterization		Salt test			Salinity (ppt)
	peeling	blast off	Chloride	Sulfate	Nitrate	
Aussa.* 1	✓	-	-	-	-	0.1
o outer surface o right side o direction : N o ~1.35 m. from rock basement						
Aussa. 2	✓	-	-	-	-	0.0
o outer surface o back side o direction : W o ~1.35 m. from rock basement						
Aussa. 3	✓	-	-	-	-	0.0
o outer surface o left side o direction : S o ~1.35 m. from rock basement						

* Aussa. is a abbreviation of Aussadangkhanimit Temple

Table 4.8 Salt test data and salinity values (Cont.)

Sampling site no	Damaged characterization		Salt test			Salinity (ppt)
	peeling	blast off	Chloride	Sulfate	Nitrate	
Aussa.* 4	✓	-	-	-	-	0.0

- outer surface
- front
- direction : S
- ~1.35 m. from rock basement

* Aussa. Is a abbreviation of Aussadangkhanimit Temple

4.5 Discussion and Conclusion

According to Puhringer's theory, the heritage deterioration is because of wetting and drying it was reported that drying and wetting is often enhanced by temperature, wind and so forth (Lubelli et al., 2006). These results are assumed that physical factors which related to the heritage deterioration are temperature, humidity and wind.

Also, the masonry materials have been deteriorating from physical factors. Many studies stated that moisture from rising damp and/or was a major cause of deterioration (State Heritage Branch, 1997 ; Heritage Council of NSW, 2008). Some researchers also reported that rising damp related to the properties of lime as 'transpiration' (Young, n.d.; Baglioni, 2009) or 'unbreathable' (US Heritage Group, Inc.,2009).

Breathable or transpiration of lime plaster is the process that concerned with water permeability or the overall movement of fluids throughout a material (Pavia et al., 2006). Many studies reported that the rate of the permeability was depended on materials circumstance. The process was began whenever the lime plaster absorbed moisture from atmosphere or it pull up underground water by capillary force which was called rising damp.

Rising damp will be rising until it can evaporated from the lime plaster. The area which rising damp evaporated was called evaporation zone which normally about 0.5 - 1.2 metres from ground (Heritage Council of NSW, 2008). Anyway, some cases of the research identified that the moisture attacked the lime plaster might be influenced from falling damp too, so for more precise the study could developed by increasing measurement points.

Anyway, according to these study. The relation of humidity and light intensity was simplified the results as Figure 4.9.

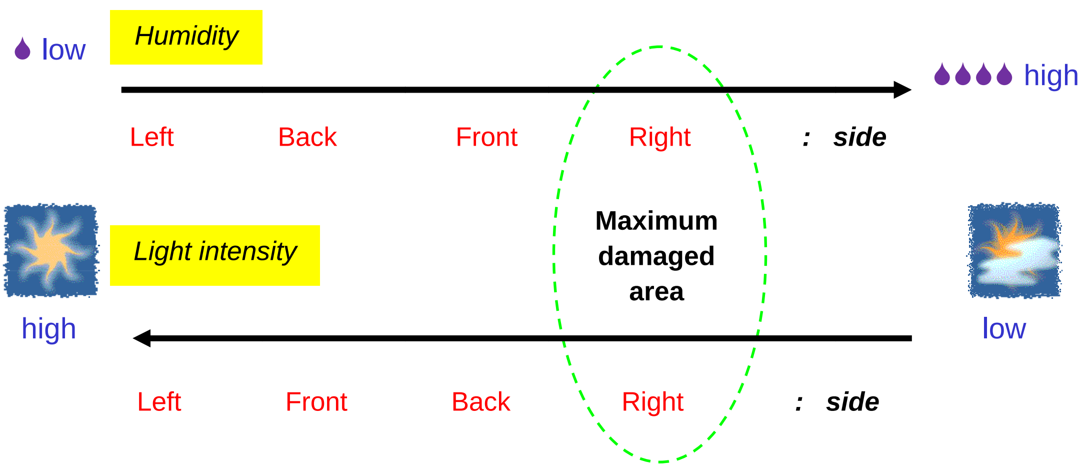


Figure 4.9 The result diagram of humidity and light intensity values

Also, this experiment was operated to confirm the mentioned results by using application program to calculate damaged points .

As the results, two interesting cases of the relation study of abiotic factors and its effect on lime plaster damaged at Apirom residence were at the wall on the left side and the right side of the building.

The data showed that the left side of Apirom residence was exposed to the high light intensity, whereas it had the low humidity values. On the other hand, the right side exposed to the low light intensity with the high humidity.

These data were compared with the damaged area of each side. It was found that the right side of the building had been deteriorating much more than the left side.

Right side

Damaged area = 1.24 ± 0.2
% RH = 41.8 ± 20.2
Light intensity = 178 ± 4

Left side

Damaged area = 0.00
% RH = 10.5 ± 2.2
Light intensity = 1,361 ± 1

Figure 4.10 The comparative of abiotic factors affecting on the right and left sides of Apirom residence

With respect to the data, in situ photographed investigation was taken. The damaged area on the plaster wall surface at the left side of the building was larger than the damaged area on the surface at the right side. These images supported the data of the light intensity calculated by image processing and the humidity measured by moisture meter (Table 4.7, 4.8, Figure 4.10)

For the front and back sides of Apirom residence, it was found that the front side was exposed to light intensity also obtained humidity much more than the back side (Table 4.7). These results were conformed with their damaged areas (Table 4.8).

Eventually, all data seem to indicate that physical factors such as humidity and sunlight intensity including the wind are the impacts on lime plaster deterioration.

Additionally, many reports stated that most historic sites which located in coastal sites were affected by salt aerosols precipitation for coastal site, saline soil or/ and salt naturally occurring in materials (Cataldo et al., 2005; National Green Specification, 2008). The data of damage type of lime plaster were also shown in Table 4.9.

Table 4.9 Some factors that cause damage to original mortar and plaster and damage types (Acun and Arıoglu, 2006)

A. The Destructive Effects of the Environment		
Factor	**Effect**	**Damage Type**
Acidic waters (with CO_2, SO_2) that come with rain or snow water.	Dissolve the carbonates of lime binder.	Adhesion and Cohesion features of the mortar is decreased. Aggregates are decomposed.
The continuity of freezing/thawing cycles.	The bonds of the mortar among the binding aggregates are dissolved.	Leads to the dissolution of the mortar.
Exposion to extreme amount of water vapour (in case of fire).	The critical water vapour content the mortar can carry is exceeded.	Leads to the hanging of the mortars in folds through decomposition.
If the sand used in mortar has clay in content.	The swelling of clay in a moisturous environment, leading to internal stresses.	Crumbling of the mortar is observed, regional swellings and draping are seen.
Sea water, air pollution, use of dirty material.	Anionic salt crystals i.e. Chlorur, Sulphates and Nitrates are formed.	Decomposition of the mortar, deep cracks nad draping of the mortar are observed.
Formation of plants	Especially some plant roots lead to the dissolution of the mortar.	Biological decay, colouring of the mortar and dissolution.
Existance of organic growth	With the formation of insects, the binding quality of the mortar is reduced.	Microbiological decay and dissolution of the mortar.
B. The Destructive Effects of the Repair Mortars		
Factor	**Effect**	**Damage Type**
Using more cement than lime.	Formation of highly stiff mortar, cracking.	Shrinkage cracks and diffusion of water through cracks, drapings due to different work.
Salts that may come from the cement.	Efflourescence on the surface of the mortar.	The salts cause the efflourescence and lead to internal stresses.
Adding synthetic resin, (if it is too much).	The water and vapour permeability regime of the original mortar is deteriorated.	Dissolution in the form of shells on the surface of the mortar.

This research was found that some deterioration characteristics as mentioned in Table 4.9 occurred in the study site. The damage status of lime plasters were related to salinity value. It can say that high salinity induces more damage status.

The results of this research supported the previous studies about the effect of salinity, exept the result from Aussadangkhanimit Temple where the salinity in damage areas was not detected. This might be because the temple was located far from the sea and situated in the open area. The temple was directly contacted to rainfall that can wash salt aerosol precipitation out off the building.

Beside, the salt damage was enhanced by chemical character of cement itself and by the coating over lime plaster surface. Usually cement has salts mixed in its combination such as sodium sulfate which can crystallize within the lime plaster. The lime plaster surface, which coated with unbreathable coating and located in the area without wind and sunlight, will have more severe damage from the salt crystals. This phenomenon is called "Cryto-florescence" that plaster surface bursts out caused by the salt crystal pressure with the surface (EU scientific officer, 2007).

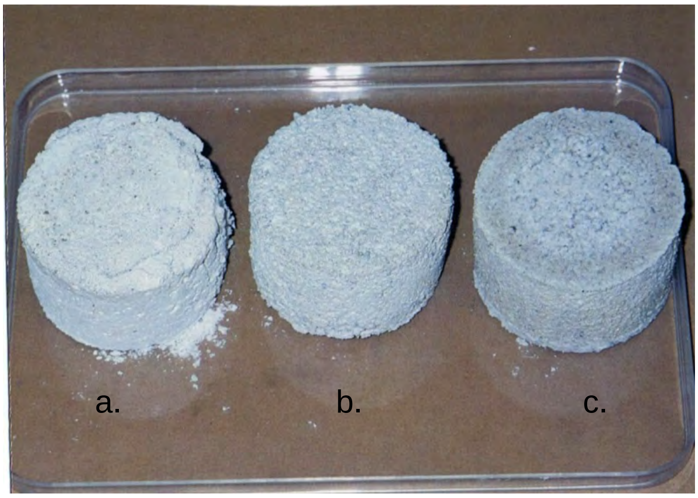


Figure 4.11 The damaged characteristic of lime plaster or lime mortar : a. Cypto-florescence b. Control and c. Efflorescence (Sirinaree Ngencharoen, 2004)

It is worth pointing out that rendering light intensity calculated by image processing provided the results useful for approximating the damage areas on the walls outside the building. For the better results, the data of other factors such as trees shading, soil salinity, land wind direction should be overlaid or input to the application program. Besides, it can conclude that lime plaster deterioration related with salinity. The degree of its deterioration are depended on site location and physical factors such as light intensity including wind that might be the other factor that supporting the breathable of lime plaster.

CHAPTER V

THE INVESTIGATION INTO BIODETERIORATION OF CHUDHADHUJ PALACE MUSEUM

5.1 Introduction

Biodeterioration or bioweathering was defined as any undesirable change in the properties of a material caused by the vital activities of organisms (Hueck cited in Allsopp et al., 2004). The organism quite simply disrupts the material by growth or movement. It is one of the principal fields of interest for researchers in the conservation of cultural heritages (Mohammadi and Krumbein, 2008).

It is associated with chemical and physical mechanisms and also it could be enhanced by environmental factors (Wiktor, 2006). The environment has a role in the type and extent of material decay because relative humidity, temperature, natural and anthropogenic pollution enhance the effects of biodeterioration (Herrera et al., 2004).

For Chudhadhuj palace museum, many organisms have been found. Some local species were found regularly but some were found seasonally. They might be influenced by temporary surrounding.

5.2 Objectives

The objectives of this study were to investigate biotic factors that might cause the biodeterioration, including to examine the deteriorated characterization which focused on the structural materials in Chudhadhuj palace museum.

5.3 Materials and methods

5.3.1 Survey of biodetrioration caused by the biotic factors at Chudhadhuj palace museum

In situ, preliminary investigation of the deteriorated characterization caused by biotic factors was carried out in every residence of Chudhadhuj palace museum such as Wattana residence, Phongsri residence, Apirom residence and Aussadangkhanimit Temple to observe and classify significant problems.

Types of deterioration problems were recorded by taking photograph, measuring parameters and collecting some samples. The problems were classified and the most severe cases were selected to study degradation characteristics.

5.3.2 Water repellent treatment against fungus stains

The study was conducted on a wall at the base of Aussadandkhanimit Temple. The wall was cleaned and removed its fungi stains using bleaching solution, Hyter®, then left to dry. The bleached area was divided into six small areas equally using a black pencil. A water repellent emulsion, TOA®, was applied onto the three alternative areas whereas the other three small areas were left naturally and used as controls. This experiment was left for six months, after that the bleach areas was photographed. The picture was used to compare the effectiveness of water repellent coating by visual observation.

5.4 Results

5.4.1 Survey of biodeterioration caused by the biotic factors at Chudhadhuj palace museum

Preliminary study carried out by direct visual observation in situ revealed that various characterization of the biodeterioration problems caused by biotic factors occurred in Chudhadhuj palace museum.

The observed biodeteriorations were presented in Table 5.1. The list also showed the types of biodeterioration problems and the occurrence sites

Table 5.1 The biodeterioration problems in Chudhadhuj palace museum

Biodeterioration Problems	Site					Total amount **				
	Green wooden	Wattana	Phongsri	Anirom	Aussagangkhanimit	1 - 5	6 - 10	11 - 15	16 - 20	> 20
Nests of birds	✓	✓				✓				
Nests of insects	✓	✓	✓	✓	✓					✓
Nests of ants	✓				✓	✓				
Excrement of birds	✓	✓	✓	✓	✓					✓
Excrement of reptiles (lizards and geckoes)		✓	✓	✓	✓					✓
Growth of plant, weed		✓			✓	✓				
Growth of fungi		✓	✓	✓	✓					✓
Carcass of snails					✓		✓			
Carcass of millipede *			✓	✓	✓					✓
Carcass of insects	✓	✓	✓	✓	✓					✓
Emigrant insects	✓	✓	✓	✓	✓					✓
Emigrant millipedes	✓	✓	✓	✓	✓					✓
Emigrant reptiles				✓	✓				✓	
Garbage from visitors	✓	✓	✓	✓	✓					✓

* Found in Chudhadhuj palace museum during rainy season;

** The classification the biodeteriorated ; [orange] Obviously affecting on heritage material [yellow] Trivial affecting on heritage material

The occurrence of insects nests, excrement of birds and reptiles and fungi stains were categorized to the significant biodeterioration problems in the museum. These problems were selected to investigate and describe their degradation characteristics.

1) Nest of the insects

The most insect species which their nests were found is wasp, Order Hymenoptera, which are a major order of holometabolous insects. Their nests generally found in this study seemed as soil stains. It was found on wood also lime plaster, approximately 2 centimetres but occasionally the nests about 30 centimetres were found (Figure 5.1). However, they preferred to nest on the shady and flat surfaces. This investigation was observed and also compared the amount of the nests on lime plaster, focused at Apirom residence. The results revealed that the wall surfaces with slightly humidity and shaded including the wood lattices and crevices were preferable areas for nesting.

Figure 5.1 The characterization of insects nests on structural materials

Figure 5.1 The characterization of insects nests on structural materials (Cont.)

Figure 5.2 Tree branches enhancing the insect nests

2) Excrement of the birds, lizards and geckoes

The excrement of birds and reptiles (Figure 5.2) were collected and measured salinity and pH value. The data were listed in Table 5.3.

Figure 5.3 The characterization of pests excrement

Table 5.2 The pH - value and salinity value of the excrement

Excrements Type / Values	Birds	Reptile (lizards, geckoes)
pH	6.4 ± 0.01	6.8 ± 0.01
Salinity	1 ± 1 ppt	0 ± 1 ppt

The results showed that the excrements were weak acidic that might be cause deleterious effects to the heritage materials such as lime which comprised of calcareous compound.

3) Fungus stains

Aussadangkhanimit Temple was investigated and severe fungus stains on the walls were found (Figure 5.3).

In situ, fungus samples from the wall were swabbed, using cotton bud and then streaked on the agar plates. The samples were analyzed and identified the predominant fungus species. *Aspergillus niger*, *Penicillium citrinum*, *Cladosporium cladosporioides*, *Nattrassia mangiferae* and non-sporulating mold (Hyphae septate, hyaline not produced conidia) were the identified fungi found on those walls.

Figure 5.4 The characterization of fungi stains at Aussadangkhanimit Temple

5.4.2 Water repellent treatment against fungi stains

The photographs taken from the bleached area were shown in Figure 5.5. By visual observation, the three areas coated with water repellent were brighter than the three uncoated areas. This indicated that the water repellent emulsion could be used to protect the cement walls from fungus stains

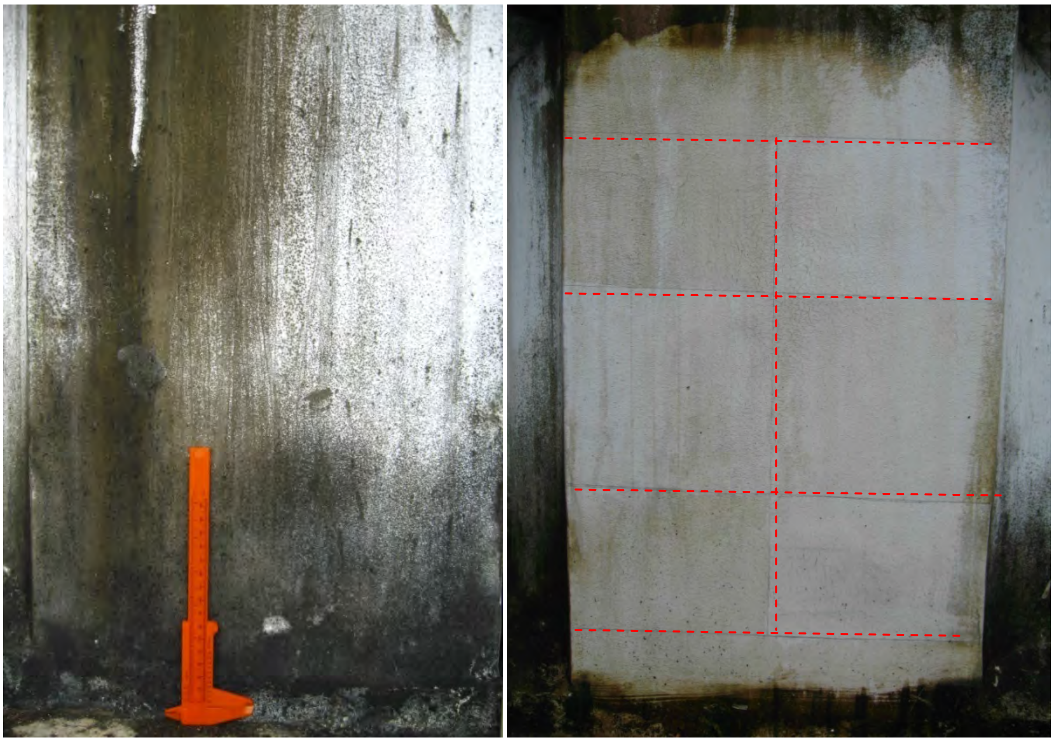


Figure 5.5 Water repellent treatment on lime plaster (South east side)

5.5 Discussion and Conclusion

Predominant biodeteriration of structural materials in Chudhadhuj palace museum were comprised. Insect nest infestation was the major threat at Chudhadhuj palace museum. The result was also reported that insect nests were found highly threatening on art objects (Koestler et al., 2000).

Excrement of reptiles and insects, were also important threats in the heritage buildings. It was found that the excrements were weak acidic substances which might be impact on inorganic material especially, calcareous materials such as lime plaster.

Eventually, the microorganism such as fungi contaminated on walls caused severe damages. The black stains on these heritage materials was resulted by fungus growing. Aspergillus niger is a fungus species that can produce melanin pigments inside its mycelium. These black spots are difficult to remove (Gomoiu et al., 2004). However, the funus attains can be protected using water repellent.

CHAPTER VI

DISCUSSION AND CONCLUSION

The environmental conditions play a significant role in determining the deterioration of historical materials, both organic and inorganic substances especially in the case of cultural sites located in warm or humid climate regions (Chiraporn Aranyanak, 2001). This assumption may also relate to Chudhadhuj palace museum, the historical heritage which has been strong deteriorating as if considered from the precipitation and temperature (Figure 6.1). Because oceanic climate could enhance the decomposition rate of the cultural heritage, so Chudhadhuj palace museum should show stronger decomposition rate, comparing to the other cultural heritage located inland.

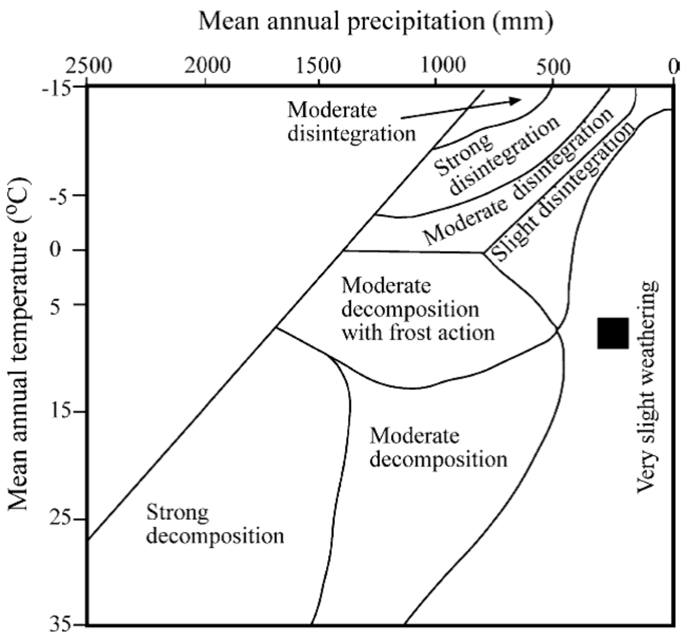


Figure 6.1 Relationship between climate and type of weathering (Fookes et al., 1970)

The deterioration problems in Chudhadhuj palace museum were carried out and clearly presented abiotic factor as light intensity affecting on historical stone and lime plaster. The weathering degree influenced by the amount of light intensity including exposure period could be estimated by image processing, a new technique method.

The advantages of this technique are reliable and comfortable. However, this study was operated by using only one factor, light intensity. More dependable results, it should be developed this method by using the other factors such as wind direction and trees shading.

Furthermore, this study indicated that salt weathering was occurred on structural materials not only on lime plaster but also stone inscription. Salt weathering can induce or accelerate chemical aging of materials concerning the mechanical damage.

As the result of this study, it would be agreed with the opinion that the fluctuations of temperature and relative humidity including prolonged exposure period of high humidity will promote fungal activity (Maekawa et al., 2007). Likewise, microbial growth relates to the moisture content of materials because it determines the water available for the germination of spores (Valentine, 2007).

For more effectiveness of the prevention, restoration and/or maintenance, it has to understand the relevant factors which concerning to the alteration, damage, demolition, development (NSW Heritage Office, 1996) which affecting deterioration of the Chudhadhuj palace museum.

Recommened by ICOMOS Scientific Council, toolbox of that factors which ought to adjust for Chudhadhuj palace museum were reported as following,

Table 6.1 Toolbox of the factors affecting deterioration on the cultural heritage (Modified from ICOMOS, 2007)

<table>
<tr><th>Monitoring</th><th>Research</th></tr>
<tr><td>Setting up a series of data gathering techniques:
▪ Air temperature
▪ RH, internal and external
▪ Ground temperature surface
▪ Ground temperature minus 1 m
▪ Ground moisture content
▪ Monument wall temperature
▪ Monument moisture content
▪ Low/high tide marks
▪ Mobilization of salts
▪ Proportion of soluble salts
▪ Quality of water
▪ Technical data
▪ Meteorological data (precipitation amount and pattern, freeze/thaw, maximum/minimum temperatures, wind velocity and direction, altitude)</td><td>▪ Case studies
▪ Condition assessment, current compared to historic
▪ Local, regional and international comparative studies
▪ How is it affecting the populations and intangibles
▪ Demographics
▪ Loss of traditional knowledge
▪ Development of local/regional research strategies to identify potential research
▪ questions to drive investigation and salvage of archaeological sites that will be lost as a
▪ result of GCC</td></tr>
<tr><th>Advocacy</th><th>Training</th></tr>
<tr><td rowspan="3">▪ Prioritisation
▪ Publication
▪ Sensitivity and public awareness
▪ General education
▪ Government partnerships
▪ International partnerships
▪ Regional workshops towards dissemination
▪ Lobbying
▪ Outreach to civil society</td><td>▪ Regional workshops for professionals
▪ Training for specific phenomena changes
▪ Conferences
▪ Training of emergency service</td></tr>
<tr><th>Risk Preparedness</th></tr>
<tr><td>▪ Plan
▪ Unifying emergency services
▪ Inspection regimes
▪ Security types
▪ Observatories lookouts (teams of people)
▪ Mobilize civil society</td></tr>
</table>

Table 6.1 Toolbox of the factor affecting deterioration on the cultural heritage (Modified from ICOMOS, 2007) (Cont.)

Maintenance		
▪ Environment ▪ Maintenance monitoring programs ▪ Management		
Built environment and in use ▪ Maintain building envelope systems ▪ Foundations ▪ Rainwater management ▪ Wastewater management ▪ Boundary/building perimeter	*Un-conserved archaeology* ▪ Survey and research aimed at identifying the range, nature and location of archaeological sites ▪ Documentation and recording ▪ Backfilling ▪ Shelters ▪ Shelter coating ▪ Capping ▪ Introduction of drainage	*Conserved archaeology* ▪ Monitoring ▪ Research ▪ Maintenance plan ▪ Interpretation that the explains the relationship of the site to the changing environment, which might also include reference to other sites that have been lost

According to the toolbox (Table 6.1), this study was concentrated on the monitoring step which studied temperature, moisture content, monument wall temperature, mobilization of salts, proportion of soluble salts and some meteorological data.

Based on the National Heritage management principles (Australia's National Heritage, 2000), the principles are as following,

1. The objective in managing National Heritage places is to identify, protect, conserve, present and transmit, to all generations, their National Heritage values.

2. The management of National Heritage places should use the best available knowledge, skills and standards for those places, and include

ongoing technical and community input to decisions and actions that may have a significant impact on their National Heritage values.

Also, It is important to remind, that retained the deterioration factors of heritage should be managed by the way as Figure 6.2

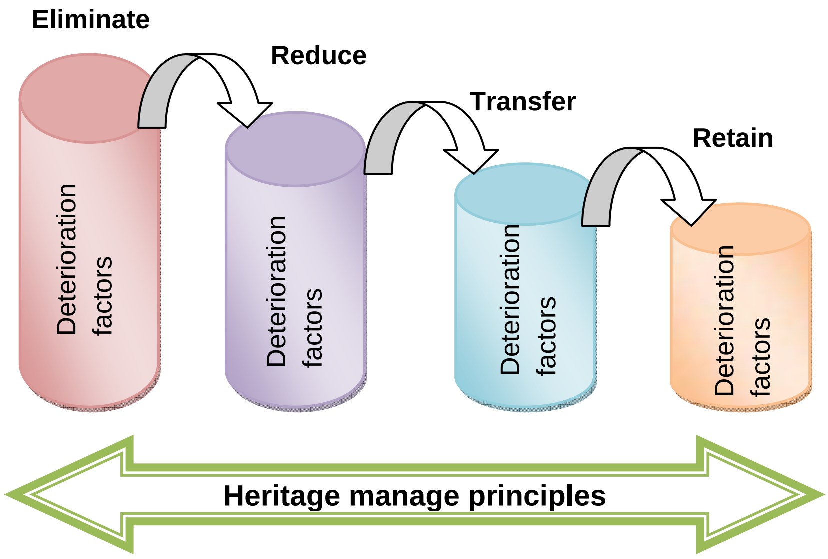


Figure 6.2 Basic phase to manage the deterioration factors of cultural heritage (modified from Horyna, n.d.)

Thus, the maintenance methods were divided by the heritage materials into two main types, the first was lime plaster and/or lime plaster and the second type was historical stone inscriptions. By the way some of suggestion were collected and presented as follows (Garrod, 2001),

Material : Lime plaster or lime mortar

Problems : Efflourescence, crypto-flourescence

- Improve site drainage and landscaping to deflect rainwater and underground water away from the building, particularly the walls.
- Eliminate obvious deficiencies in the design or construction of the building and surrounds, to stop water ponding on or near the walls.
- Improve under-floor ventilation, if possible. This will reduce the moisture reaching the walls.
- Establish good maintenance and housekeeping. Fix the roof, leaking pipes and drains. Why let unnecessary moisture enter the walls?
- Remove coatings and membranes that prevent evaporation from the walls. Let nature reduce the moisture load in the walls.
- Reinstate the damp-course either with water repellent coating such as siloxane liquid or by undersetting, if needed.
- Set up point of evaporated zone or capillary setup.
- Damp proof course (DPC)
- Bentonite packing

Problems : Fungus stain

- Cleaning out
- Fly ash solution (Degirmenci and Baradan, 2005)
- Water repellent

Problems : Excrement of bird or reptile

- Cleaning out by gently detergent.
- Prevention the clinging areas by sieve, nail or knot.

Problems : Nest of insect or bird

- Remove undesirable vegetation and prevent its spread.
- Remove the nest from material surface.
- Nest zone induction
- Controlled atmospheres.
- Natural plant products
- Biological methods

Problems : Weathering

- Nanometric slaked lime (Dei and Salvadori, 2006)
- UV stabilizer
- Polymer modified cement – based repair mortars (Mirza et al., 2002)

Problems : Salt damp (modified from Department for Environment and Heritage, Heritage South Australia, 2007)

✓ DO check gutters and downpipes for overflows, leaks, blockages, and for signs of water pooling against walls - best to do while it's raining. Fix leaks promptly and improve site drainage where possible.

✓ DO wherever access is possible, check under timber floors and framing, as damp walls increase the risk.

✓ DO investigate whether your building or structure has had previous treatments that may be obscuring the extent of the problem (for example areas of render over masonry) - a thorough investigation of the current state of things will better inform the nature and extent of any repair or remedial works.

- ✓ DO clean out existing air vents regularly, and monitor the results before installing new ones or changing ventilation conditions.
- ✓ DO get independent, professional advice.
- ✓ DO consider carefully the implications of drying out the soil beneath your building - places built on clay soils are prone to structural cracking when the soil goes through extreme moisture differences. Each case will be different, but generally a consistent moisture content in the soil will provide a compromise between cracking and rising damp.
- ✗ DON'T use hard, cement rich mortars to repoint failed mortars, which will not solve the problem and will increase the risk of further damage.
- ✗ DON'T ever seal old masonry walls with water repellent coatings.
- ✗ DON'T allow garden beds to encroach up to and along walls controlled irrigation to avoid moisture spray and ponding near the walls is best (drippers are better than sprinklers for this reason).
- ✗ DON'T employ the contractor with the cheapest price without informing yourself of their method and track record - a cheaper initial price can become far more costly in the long run due to poor workmanship and cutting corners.

Material : Historical stone inscription

Problems : Sea aerosol precipitation

- Water repellents
- UV stabilizer

Problems : Weathering

- Shelter shading
- Lasers cleaning (Salimbeni et al., 2000)
- Replace the stone inscription with simulated stone inscription and move the antique stone inscriptions into suitable area.
- Reinforcement by consolidant and/or water repellents (Garrod, 2005)

(1) Silane - based solution :

Silane-based solution are generally organosilicon compounds which polymerize inside the stone. Some water is needed to aid the reaction, but the amount is critical; a high humidity means the reaction may take place too quickly and too much water leaves no space for the polymer to form. Penetration can be quite deep, but this depends greatly on the product used and the conditions in which it is applied.

By the production of silica, there is a definite consolidating effect and many silane-based products seem to increase the strength (flexural, compressive, tensile etc) of damaged stone. (Figure 6.2)

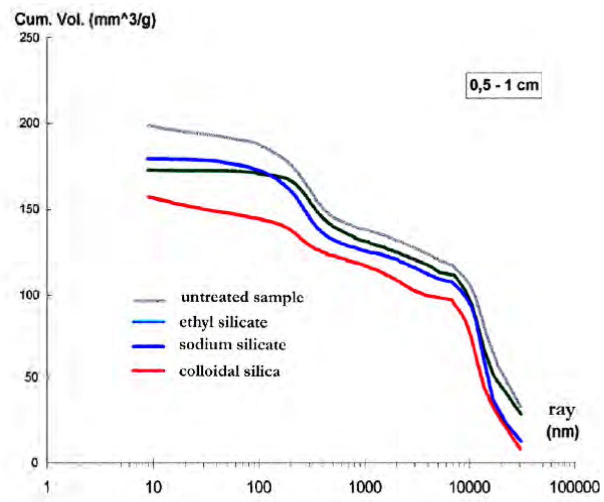


Figure 6.2 Cumulative volume curve of the different products at 0.5 -1 cms. depth (Zendri et al., 2007)

Unfortunately, there is some color change with most types of silanes. although studies show that this usually lessens after about 18 months. Porosity, water absorption and pore size distribution have shown to be affected by the treatment, a little in some cases and a lot in others. This influences resistance to salt crystallization and freeze/thaw action. Where there is a new area of stabilized decayed material, moisture evaporation has to take place within the stone and this may lead to salt crystallization at the boundary between treated and non-treated stone.

These are the main silane-based products and their main features:

- tetraalkoxysilanes - have little water repellency.
- alkyl trialkoxysilanes (such as brethane) - less consolidation, but good water repellency.

- polysiloxanes-flexibilityand more water repellency.
- silicon hydrides - use presents many health and safety problems.
- halogen bearing silanes - generate damaging acids, so thought to be too dangerous.

(2) Organic-based solution

These solutions can be applied by themselves or dissolved in an appropriate solvent. They generally have good adhesion to the substrate and are good at taking up dimensional changes in stone (such as thermal expansion and contraction). The disadvantage of using organic-based materials is that they can be vulnerable to heat or ultra-violet (UV) light and generally the penetration depth depends greatly on the ability of the solvent to carry the consolidant into the stone and the percentage of moisture in the stone. Many products have a very low penetration depth.

These are the main organic-based products and their main features:

- acrylic consolidants - there can be some colour changes.
- vinyl consolidants - very unstable in heat and light and tend to pick up dirt.
- epoxies - the treated stone will be prone to yellowing and the appearance of a white powder.
- polyurethanes - can alter the properties of the stone it is applied to, including strength, porosity, and brittleness; polyesters - have an

extremely poor resistance to UV radiation and acid rain; not ideal for stone conservation.

- perfluoropolyethers - good water repellents, their advantage in stone conservation is the fact that they are reversible and stable in UV light, but they have limited cohesive properties.
- fluorinated elastomers - water absorption, vapors permeability and porosity can be altered by them, but cohesion is good.

(3) Inorganic treatments

- fluorosilicates - cannot be used on limestones since they react badly with calcium carbonate, and they are not very effective on sandstones.
- barium-hydroxide - there is sometimes a color change, but it can be a very good consolidant if applied correctly and kept wet for an accurate amount of time; limewater - an old product that is still in use, it is reversible and simple to use .

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