CONSERVATION TECHNICAL HANDBOOK

A GUIDE FOR BEST PRACTICES

Volume 2 | Roofs

ICOMOS SINGAPORE
URBAN REDEVELOPMENT AUTHORITY

Conservation Technical Handbook
Volume 2 | Roofs

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Cover photography by Jeremy San Tzer Ning, courtesy of the Singapore Heritage Society: metal roof of Maris Stella Chapel

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Preface

Urban Redevelopment Authority, as the national land use planning and conservation authority, is pleased to present this series of conservation handbook. Through judicious planning, Singapore has conserved more than 7,000 buildings and structures since 1989. They cover different building types, architectural styles, scales and genres. They are our precious legacy that must be protected for current and future generations of Singaporeans.

This series is a culmination of URA's collaboration with ICOMOS Singapore, our local chapter of the International Council on Monuments and Sites. This worldwide non-government organization is the official Advisory Body to UNESCO, advising the latter on heritage, conservation and preservation matters and issues. It taps on the technical expertise and experience of ICOMOS Singapore members to take the protection of our heritage gems to a higher level.

The eight volumes in the series are designed as step-by-step guides to carry out best practices in conservation. They will aid those undertaking works on heritage buildings. They contain a wealth of insights gleaned from projects in and around Singapore, taking into account climatic conditions, materials available in the market, new techniques brought by technological advances, and the types of skills offered by the industry.

I hope building owners, developers, professionals in the industry, builders and others who are interested in this field will find this series rewarding. I believe we can foster a strong partnership to protect our heritage. Together, we can make Singapore not just a distinctive liveable city, but also a home that holds meaning for us all.

Chou Mei (Ms)
Group Director (Conservation & Urban Design)
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About This Series

Since the 1970s, when historic monuments were first granted legal protection and the first shophouses were rehabilitated, architectural conservation has evolved and taken root in Singapore. Heritage buildings form a significant part of our urban landscape today, as brick-and-mortar repositories of memories straddling generations and as treasured focal points for diverse communities.

In the early days, the main challenge was overcoming the prevailing perception of these historic buildings as crumbling, unsanitary and inefficient structures worthy only of demolition (though in need of rehabilitation, they are embodiments of artisanship, history, and urban character). Another uphill battle was the polarized view that conservation is a zero-sum game in terms of economic growth and urban development (it is an indispensable component in all creative, dynamic, well-loved, liveable and competitive cities).

While much progress has been made and lessons learned in the past four decades, there is still much room for improvement in skills and knowledge of best conservation practices. This guide is intended to help bridge this gap by laying out the ways to identify and appreciate heritage attributes, understand historic materials and assess their condition, as well as the methods and principles of restoration and long-term maintenance.

Built heritage can be seen as a public good, and every stakeholder – including the owner, developer, authority, building professional, builder and user – serves as a custodian of these precious assets. There is shared responsibility to safeguard each historic structure and ensure its safe passage onwards to the next generation. This series is conceived to provide guidance along the way.

Dr Kevin Y.L. Tan
President
ICOMOS Singapore

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Look out for margin notes such as this one, which will give you further advice or link you to other parts of the book.

What do the icons mean?

- General tips and advice
- Concepts learnt in other chapters or volumes
- Worksheets are available
- External references
- Further reading and topical notes

About This Volume

Volume 2: Roofs is the second book in a series of eight **Conservation Technical Handbooks**, and presents some of the main roof types, components, and covering materials commonly found on historic buildings in Singapore.

Chapters 1 and 2 provide an **Introduction** of how different parts of the roof come together, as well as the three main types of **Roof Structures** – timber, metal, and reinforced concrete. General notes on roof conservation and maintenance that applies to most roof types are included at the first chapter, and should be referred to in addition to the information specific to particular roof types in subsequent chapters. Refer also to Volume 4 Structures for roof structural issues and conservation strategies.

Chapters 3, 4 and 5 are organised according to the three main historic **Roof Covering** categories – tiles, metal, and reinforced concrete, so that you can quickly refer to the relevant sections as and when you encounter a particular material.

Chapter 6 focuses on **Ceilings and Soffits** as the 'undercroft' of the roof system, whose condition and problems are closely related to and affected by that of the roof, while **Chapter 7** takes a brief look at the common types of historic **Roof Accessories and Ornaments** found in Singapore.

The contents of each chapter are organised under five key headings:

Overview: This section usually provides a historical background to the element or material and the common variants found here, including how or why these came to be used in particular ways in Singapore's past building practice.

Common deterioration: Roofs play the main role in a building's basic function to shelter. This section lays out common types of roof defects and their causes, especially due to constant exposure to weather, and other issues associated with roofs that building owners may face when conserving or repairing their building.

Diagnostics: This section provides methods for inspecting and diagnosing issues in the roof element or material. Where possible, both simple, do-it-yourself methods of diagnosis, as well as methods that require specialists to carry out are provided.

Conservation and Intervention: This section outlines steps that are commonly taken to address causes of deterioration, as well as restore and protect dilapidated historic materials.

Maintenance: This section highlights particular characteristics of the material or element that may affect how it performs, and recommendations for long-term care and upkeep.

While specialist consultants or builders are required for many of the technical investigations and works mentioned, having a basic understanding and overall idea of what constitutes good conservation / maintenance regime would inform better management and works planning of the historic property.

Do look out also for **box stories** and **helpful tips** in the margins for more in-depth discussion of the material or element at hand.

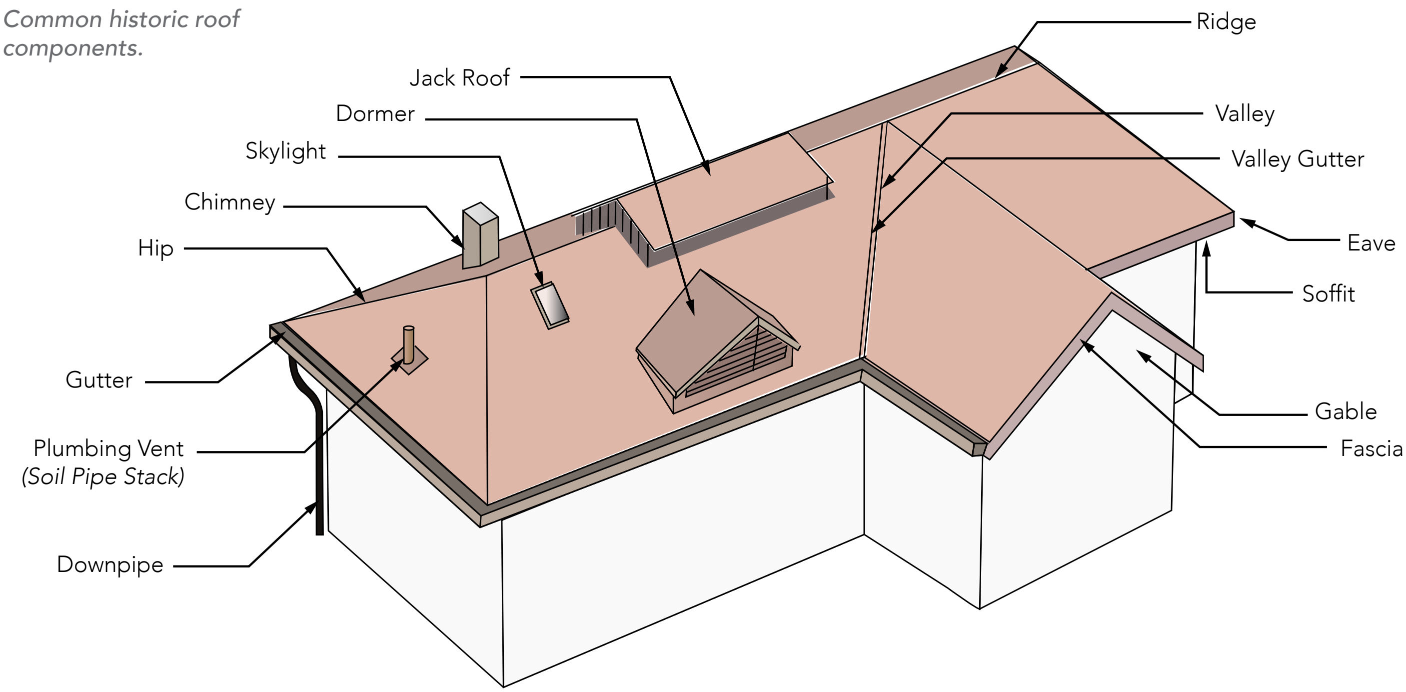
1 INTRODUCTION

Overview

The primary role of the roof is to shelter – it is the building's first line of defence against the elements. Although usually designed to withstand weathering, it also tends to be under-maintained due to limited visibility and accessibility. In historic buildings, it is important to ensure the integrity of the roof, as any sustained leakage will lead to a myriad of downstream deterioration issues, affecting vulnerable interior elements and even structures.

This volume introduces key types of roof structures, finishes, and ceilings / soffits that make up the **building roof system**, as well as roof accessories such as rainwater goods and some common roof ornaments. Basic pointers are provided on identifying common defects, conservation and maintenance works involved. These information should help with identifying the roof type and materials, key signs of defects to look out for, and main diagnostic and restoration methods available.

Common historic roof components.



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Where the historic roof finish had been replaced, looking out for any **remnant signs of the old roof framing system,** such as batten or purlin notches on retained main structural members, would likely provide some clues to the original roofing finish.

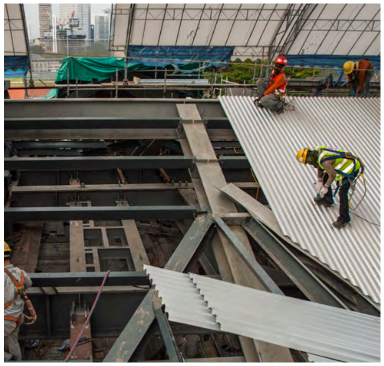
ROOF: BASIC CONSTRUCTION

Roof structures support the weight of the roof covering, wind and rain loads, as well as its own weight. Typically, the roof's structural components work to transfer the load to the load-bearing walls or columns of the building. Often it also defines the shape of the roof.

Battens are timber strips or metal channels fixed onto the upper side of roof structures to receive the roof finish, or roof cover material, and may not be in the same material as the structural members. The material, direction and spacing of battens are more closely tied to the type of roof finishes, and this in turn determines the placement and numbers of roof structural members such as purlins and rafters.

TIMBER BATTENS WITH INTERLOCKING CLAY TILES

INCLINED TIMBER BATTENS WITH V-PROFILE TILES



STEEL BATTENS WITH METAL SHEET ROOF

Left: *Interlocking tiles such as Marseille tiles or pantiles are laid on battens running horizontally across rafters.* ***Middle:*** *V-profile clay roof tiles would have very closely-spaced inclined battens running from ridge to eaves. The relatively small tile size and high number for the same roof area also meant that more battens and supporting members are needed for V-profile tiles.* ***Right:*** *Sheet-roofing, especially self-supporting corrugated sheets, can have battens that are spaced wide apart, or even be secured directly onto the main roof frame.*

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Refer to *Volume 1 page 14* for basic roof forms

CONSIDERATIONS FOR FINISHES

There is a wide range of roof finishes found on local historic buildings – from clay tiles, cement tiles, metal sheets, reinforce concrete slab or shell, to the less common metal shingles and slates.

The **roof pitch** can affect the choice of roof cover materials. For example, in a pitched roof, the shape of the structural framing affects the angle of the slope, which affects how quickly rain is able to shed off the roof. Roofs with very steep pitches will not be suitable for clay tiles that may fall off due to its weight. Flat or low-sloping roofs may need stronger structural frames to support the weight of standing rainwater, and roof covering with minimal seams to prevent seepage while the water drains off.

Some finishes or roof forms require a **substrate** or backing material. For example special roof forms such as domes may have an additional layer of timber substrate on top of the structural frame, onto which metal sheets can be moulded and secured.

In the past, roof coverings, like most building materials, were typically put to use not too far from their place of production until trade and advancement in transportation made it easier for the movement of goods. Attap leaves from the local palm *Nypa fruticans* were once widely used here as roof covering on houses, barracks, and even public buildings. The leaves are folded over a bamboo rod, stitched in place using rattan and dried in the sun to form roofing shingles. These are to be replaced every five years or so. However, examples of such organic roofing material is almost non-existent in Singapore today, apart from the occasional garden pavilion.

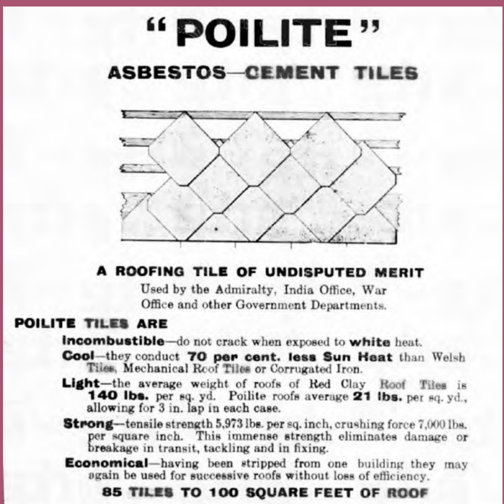
Timber substrate for securing and shaping copper sheet roofing into a dome form.

ASBESTOS

Asbestos is the collective term for a group of naturally occurring silicate minerals, known for their fire-retardant, heat- and electricity-resistance and sound absorption properties. Commercially mined since end 19th century, their fibrous crystals were incorporated into a wide range of building materials, including roofing tiles, sheets, and insulation.

By now it has been long established as a carcinogen, and that inhalation of asbestos fibres can cause serious respiratory diseases that may take years to manifest. The use of asbestos-containing materials has been banned in Singapore since the late 1980s. However, they are still found in many buildings constructed before the ban, mostly as corrugated roof sheets, ceiling boards, insulation, and partition walls.

In historic buildings or buildings erected before 1 Jan 1991, suspected asbestos-containing materials should be tested and assessed. This will include taking a sample of the material for laboratory testing by a competent surveyor. The condition of identified asbestos materials has to be assessed. Damaged or deteriorated specimens with asbestos shall be replaced – asbestos removal and site decontamination are to be carried out by Ministry of Manpower's Approved Asbestos Removal Contractor (AARC), and disposal of asbestos waste by National Environmental Agency's Approved Waste Disposal Contractor.



1917 advertisement of asbestos cement roofing tiles.

The replacement material should be similar in form, such as corrugated metal sheets, or asbestos-free cement tiles. For intact asbestos-containing finishes in good condition and not disturbed, the risk of exposure to asbestos is low. Immediate replacement is not necessary if no works are being carried out to the building. However, it will require proper management and periodic monitoring on the condition of the material to prevent exposure to asbestos. If the condition has deteriorated or the material is damaged, it should be replaced immediately. It is recommended that asbestos-containing materials should be removed when the building undergoes conservation or addition and alteration works. These could be replaced with asbestos-free replica or replacement that are in line with the building's heritage presentation.

Notes on Roof Conservation Works

In general, the key principles to roof conservation are:

- retaining the **roof profile** and **roof height**. Since roofs are a defining feature of building form, any changes in form or height critically affects the building as a whole and its heritage presentation in terms of proportion and silhouette.
- retaining the historic **roof construction** in terms of structure and finishes, where intact or viable to restore.
- in the case of **building traditions** that calls for periodic replacement of defective roof members or reconstruction, such as traditional Chinese structural carpentry, specific methods and provenance, including local adaptive variations, should be respected.

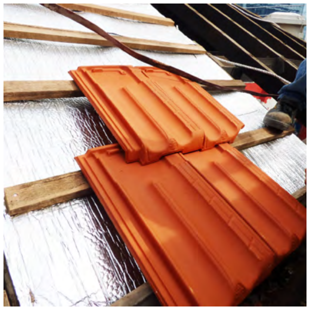
TEMPORARY ROOF

During major roof structural rehabilitation, roof cover restoration or replacement, a **temporary shelter** should be erected above the existing roof level to protect vulnerable interior elements such as timber finishes, wall ends and building components not intended for exposure to the climate. A temporary shelter is also critical to ensure an all-weather environment that allows for conservation work whether on the roof or at the exposed interiors.

***Left:** A simple pole-and-canvas temporary roof for restoration of delicate temple ceramic shardwork at Wak Hai Cheng Bio. **Right:** Mobile temporary roof mounted on tracks that can be moved according to the roof section undergoing works, at the Victoria Concert Hall.*


Interlocking clay tiles laid on metal battens atop secondary metal roof.


New flashing lining the junction between roof covering and partywall.


The new sisalation foil is secured to the rafters together with the battens above. Tiles are then laid on top as the final roof layer. Pads of rockwool would usually be added below, between rafters.

DESIGN ENHANCEMENTS

A **secondary roof** may be introduced during roof conservation in various scenarios. Historic clay roof tiles often are not able to pass roof cover performance tests for water-tightness. To retain historically significant tiles for material authenticity, one way is to introduce a new lightweight metal sheet roofing underneath that functions both as the performing roof cover, as well as a new substrate supporting the relatively fragile historic tiles. This method is sometimes also applied even when the clay tiles are replaced, often to reduce maintenance issues and to increase the load-bearing capacity of the roof.

The historic roof could also be found to have design flaws, especially for construction methods or materials that were relatively new then, or built during periods of austerity and scarce resources. For example, early reinforced concrete (RC) flat roofs may not have incorporated sufficient insulation for the tropical climate, causing the rooms beneath to overheat. In this case, a lightweight secondary roof may be introduced above the retained historic roof to reduce heat gain and improve interior comfort.

Other design enhancements may include addition or improvement of **flashings**. Usually in metal, these are sheets formed to create a discreet waterproof overlay protecting joints between the roof cover and other building elements such as partywalls, dormers, jack roofs, awnings, etc.

INSULATION

An added metal decking may lead to increased heat gain to the building interiors - this should be mitigated by sufficient roof insulation and ventilation of the roof space. During major roof conservation works, sisalation and rock wool layers are often added to the roof build-up to improve thermal and acoustic insulation for better interior comfort, as well as energy-efficiency, especially where air-conditioning is introduced to the historic building. Sisalation foil sheets also act as an added waterproof layer.

Notes on Roof Maintenance

Refer to Volume 1 for notes on maintenance. The inspection form in Volume 1 is a good starting point to looking for defects.

The inspection should include the roof space and ceilings, if possible, to assess the condition of the roof structure and to identify any trace of water ingress, such as unusual damp patches showing up at the ceiling.

Exposed and directly impacted by climatic elements, roofs are subjected to particularly stressful conditions, and prone to weathering, damage, and biological infestation. Roofs being the primary shelter of a building, any defect should be addressed and its cause determined as soon as possible to prevent the problem from worsening and affecting the vulnerable interiors.

In general, up-to-date records of construction and inspection documents should be obtained and made accessible. This will inform any future restoration works and help ensure the use of appropriate methods. Full specialist inspections should be conducted at regular intervals, typically every five years.

Leaf litter choking up roof valley gutter – unreachable areas such as this may only be detected with elevated access or via a drone recording.

INSPECTIONS

Most roofs are physically out of range for close up inspection unless safe elevated access, such as boom lift or scaffold, is available. However it is still important to carry out regular yearly visual inspections even if these are limited to just casual observation from vantage points. Given the elevated location and limited access, a pair of binoculars is usually helpful for roof inspection. Unmanned aerial vehicle (UAV) or drone may be used to complement the visual inspection by providing a global view from height and difficult to reach areas.

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Roof accessory elements to check during maintenance inspection.

Crack line across ridge beam of a traditional Chinese roof indicating structural distress.

Wasp nest under roof eave.

Refer also to the Maintenance sections in *Chapter 6 Ceilings and Soffits* and *Chapter 7 Roof Accessories and Ornaments.*

Key roof elements and related components to inspect from the exterior include:

- Roof cover
- Roof structures (e.g., exposed rafter ends at eaves)
- Roof form (any deformity or sagging)
- Roof terrace
- Eaves (including soffits and fascia boards)
- Metal flashing
- Gutters, hoppers, and downpipes
- Dormers
- Chimneys
- Lightning tapes

Sagging of the roof coverings may indicate underlying structural issues that should be further investigated. Critical elements such as flashings and rainwater goods should be checked at quarterly intervals for defects including chokage or plant growth.

Following unusual weather events (such as storms or floods), or when water seepage is observed through the ceiling below the roof space, ad hoc inspection may also be needed. Inspection for leakage is best carried out during and after rain, when the signs and location of water ingress will be easier to identify.

Given the inaccessibility of roofs, defects are often discovered only when they affect interior elements, which are more visible. As such, regular roof inspections should include immediate interior elements such as ceilings, beams and walls, and where possible, the roof undercroft or roof space should be checked, perhaps via ceiling access panels, for potential causes of failure or sources of leaks:

- Dampness patches or water marks on the underside of roof or ceiling may indicate water seepage
- Condensation and mould infestation at the underside of the roofing or ceiling boards may indicate air infiltration
- Signs of termite infestation of ceiling boards or roof timber members
- Defects of roof structural members such as rusting metal trusses or split timber roof beams
- Gaps in roof cover


Left: *Inspection of roof space between ceiling and roof covering.* ***Right:*** *Water ingress through defective roof causing ceiling stains and deterioration.*

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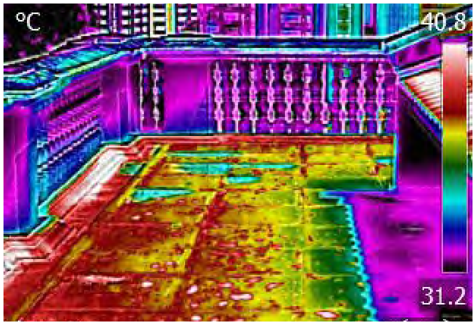
NON-DESTRUCTIVE TESTS

During a comprehensive inspection, or when leakage is suspected, non-destructive testing tools could aid in verification such as infrared thermographic survey and ultrasound leak detection, to inspect the top surface and underside of the roof to ascertain points of water ingress with good accuracy without the need for elevated access.

VEGETATION AND BIOLOGICAL GROWTH

Surrounding trees or vegetation, especially where there are falling leaves, climbers, or overhanging branches in the vicinity of roofs should be pruned. This is to prevent roof damage by impact from fallen branches, chokage of gutters and downpipes, or debris trapped on roof cover leading to biological growth or moisture-related deterioration.

Any plant growth on roof coverings should be addressed immediately. These could be trimmed and removed carefully or treated with herbicide. Forceful extraction may cause tile dislodgement or breakage, and should be avoided.



Left: *Infrared thermograph of a roof terrace – the colour temperature represents thermal variation, with abnormally 'cool' zones indicating possible moisture retention or seepage.* ***Right:*** *Trapped debris and moisture on roof creates a conducive environment for biological growth.*

2 ROOF STRUCTURES

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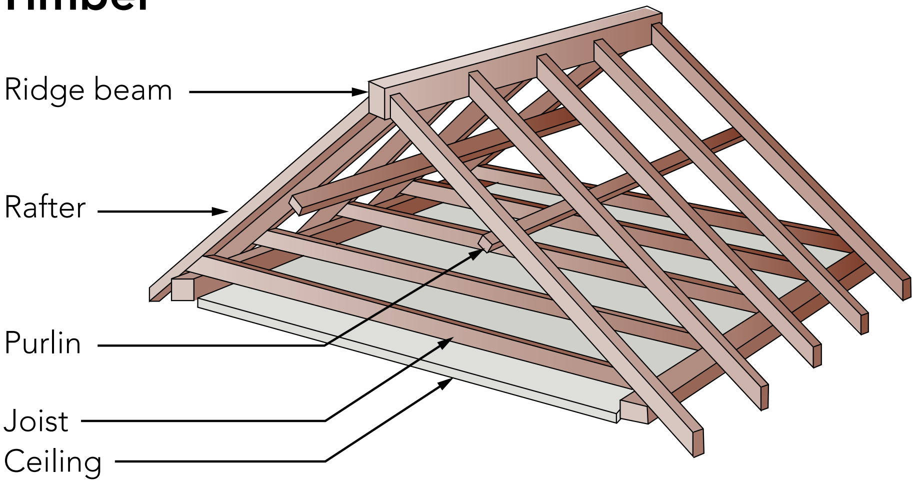
Refer to earlier section on *Roof: Basic Constructions*, and *Volume 4 Structure* for relation of roof structures to other roof components, and to other parts of the building structure, respectively.

Timber



Basic timber roof structure.

The most historic type of roof structure, timber roofs are typically found in pitched forms. Conventionally, a timber roof frame consists of rafters, joists and purlins. The rafters are hung from the apex at an angle to provide the slope, while the joists connect the bottom ends of the rafters to prevent their outward spread. The rafter-and-joist 'triangle' frame is repeated horizontally across the top of the building and connected to each other by purlins. Timber members could also be jointed and triangulated into trusses for wider spans.


***Left:** The composite roof truss of St George's Church (1913) comes with a metal tie rod providing tensile resistance, allowing a wider span while remaining lightweight.*
***Right:** Sculptural roofs, such as turrets, domes and flared ends employ the use of contiguous substrate laid on custom-crafted rafter ribs, to provide the shape and curves the roof.*

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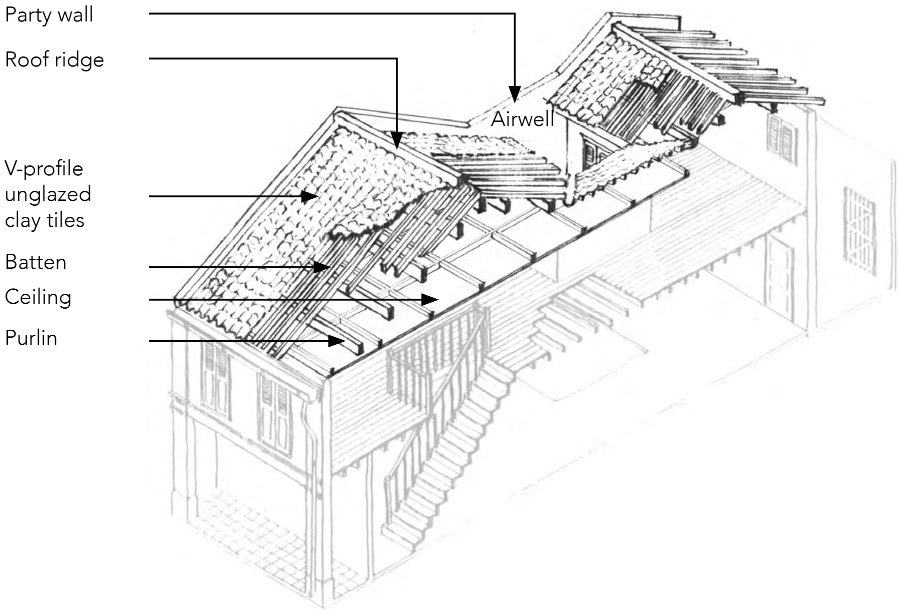
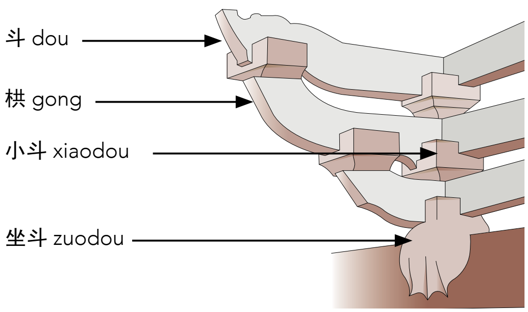


Shophouse roof system

In **shophouses** or **townhouses** with pitched timber roofs, roof beams and purlins span directly between brick masonry partywalls. A ridge beam at the peak of the roof pitch work together with the purlins to both tie and brace the partywalls in position. This is possible due to the limited unit width of each shophouse or townhouse. Ridge-to-eave battens are fixed directly on purlins to receive V-profile clay tiles; for interlocking clay tiles, conventional rafters with horizontal battens are deployed.

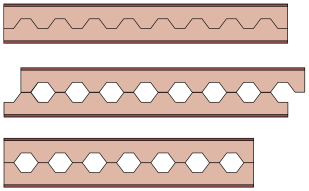
In traditional Chinese roof construction, the ***dougong*** (斗栱) system is formed by interlocking timber brackets enabling wider spanning eaves by reducing the strain on the roof beam. Examples can be seen at historic Chinese temples and houses.

Chinese dougong timber bracket roof system.



Metal

Refer to earlier section on *Roof: Basic Construction*, and *Volume 4 Structure*



Schematic showing the concept of castellated beam – deeper, and thus stronger, beams are created using the same amount of material as a conventional I-beam.

Introduced by colonial engineers, early local metal structures were erected using **imported standard manufactured components** such as cast iron pillars and trusses, and later steel beams and columns, from foundries such as Walter Macfarlane and Dorman Long.

I-beams – known in the past as "**rolled steel joists** (RSJ)", together with C-channels and L-angles, jointed by plates and rivets to form prefabricated roof trusses, were touted to be stronger, non-combustible, lighter-weight, quicker to erect and longer-spanning than timber. This made it especially popular for industrial structures, such as the steel-framed roof of St. James Electric Station (1927).

Metal roof framing enabled a variety of roof forms to be constructed with less material, weight and cost, including traditional masonry forms such as dome roofs, as seen at the former Supreme Court.

The subsequent development of castellated steel beams, with perforated web-plates and increased depth, created stronger structural members without additional material or weight.

***Left:** Castellated steel roof beams span the interiors of Church of St Bernadette (1959) by local architect Alfred Wong. **Middle:** The lightweight steel-framed roof of the St James Electric Station (1927) was brought to site in pre-fabricated components and assembled together using rivets. **Right:** Telok Ayer Market (also known as Lau Pa Sat, 1894) features cast iron pillars and roof trusses.*

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Reinforced Concrete

Refer to earlier section on Roof: Basic Construction, and Volume 4 Structure

RC roof truss details of Ellison building (1924) - cast with notches for receiving timber battens and monolithic joints.

Also known as **"ferroconcrete"** in its early days, modern reinforced concrete (RC) was a product of the Industrial Age, and first put to commercial application in late 19th century Europe. Iron rods and laths, and later steel reinforcement bars (rebars), were incorporated within concrete to create a composite building material with both compressive and tensile strengths. Unlike timber and steel where component members are jointed into a truss, an RC truss or frame is cast as a monolithic whole, providing rigidity. Riley Hargreave & Co. (later United Engineers) was one of the pioneer architectural RC builders in colonial Singapore alongside French RC specialists Brossard & Mopin.

Some of the shophouses of the early 1920s, such as Ellison Building, featured the traditional triangular-truss roof but constructed in RC. A more expressive example can be found in Clifford Pier (1933). The Church of St Teresa (1929) features RC portal frame roof, constructed by Brossard and Mopin.

The compressive strength and flexibility in form also enabled wide-spanning parabolic arch frames, as exemplified by Tanjong Pagar Railway Station (1932) and Straits Settlement Volunteer Force (SSVF) Drill Hall (1934).

***Left:** The series of two-storey parabolic arch frames at SSVF Drill Hall (1934) springs from the ground level and frames the lofty upper floor hall space, supporting a stepped profile roof with integrated clerestories. **Right:** RC arched trusses of Clifford Pier (1933) function as both the structure and the roof, providing an expanse of column free space, while the exposed trusses define the quality of the space below.*

3 ROOF COVERING: TILES

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Overview

Roof tiling comprises a wide range of materials. Raw materials are processed into small standard units that are easy to transport, handle at height, and fit to different roof forms. These are then installed on site, usually overlapping like scales, laid and/or fixed onto a substrate layer, the assembly of tiles forming a water-tight, continuous roof cover. In the local context, unglazed clay roof tiles are the most common. The subsequent sections on deterioration, diagnostics, conservation and maintenance are largely focussed on clay tiles, though many basic principles would also apply to other types of roof tiles.

V-PROFILE TILES

Handmade terracotta V-profile roof tiles, also termed **Malacca tiles**, were imported from the older colonial settlement of Malacca during Singapore's early colonial period. As Singapore does not experience strong winds, the tiles were typically overlapped and laid on rafters with minimal mortar near the roof eaves and ridges, rather than nailed down.

V-profile tiles are laid by nestling rows of upturned tiles between closely spaced inclined battens forming 'valleys', and overlapped with alternating rows of upright tiles forming 'ridges'. The tiles could also be layered on in twos or threes for added water-tightness.

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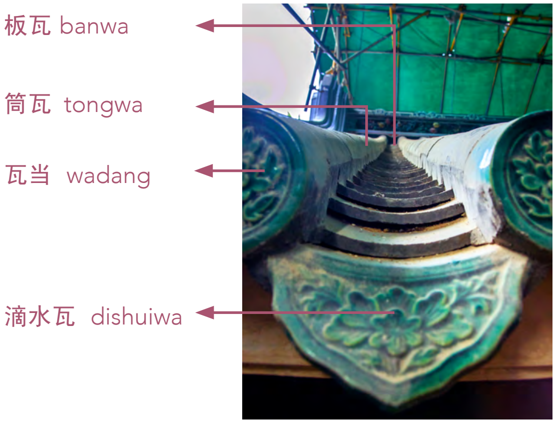

***Left:** Different tile types in the Chinese roof tiling system as seen at Wak Hai Cheng Bio. **Right:** First storey awning with green glazed Chinese tiles and granite bracket at a shophouse along Telok Ayer Street.*

CHINESE ROOF TILES

Chinese roof tiles, commonly seen on traditional Chinese architecture, such as temples and courtyard houses, are laid in a similar fashion. The most commonly used system comprised alternating rows of flat and cylindrical terracotta tiles (板瓦 banwa and 筒瓦 tongwa) running from ridge to eave. Each row of flat tiles typically terminate at the eaves with a glazed drip tile (滴水瓦 dishuiwa), and for the row of cylindrical tiles, a glazed capping tile (瓦当 wadang or 勾头 goutou). In more elaborate buildings, soffit tiles (望瓦 wangwa) were laid before the laying of the flat and cylindrical tiles. These tiles were not manufactured in the region but were likely to have been imported from China.

Apart from Chinese architecture, these are also commonly seen on the first storey awnings on shophouses or townhouses, often supported on cantilevered granite brackets. A key facade feature on shophouses that serves to shelter the five-foot-way or entrance, these canopies may also feature the same unglazed clay tile type as the main roof. The use of more costly Chinese tiles as facade accents likely indicated the Chinese identity of the building's original owner.

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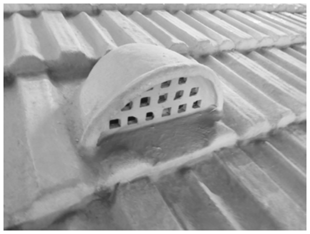
1923 advertisement of Marseille tiles.

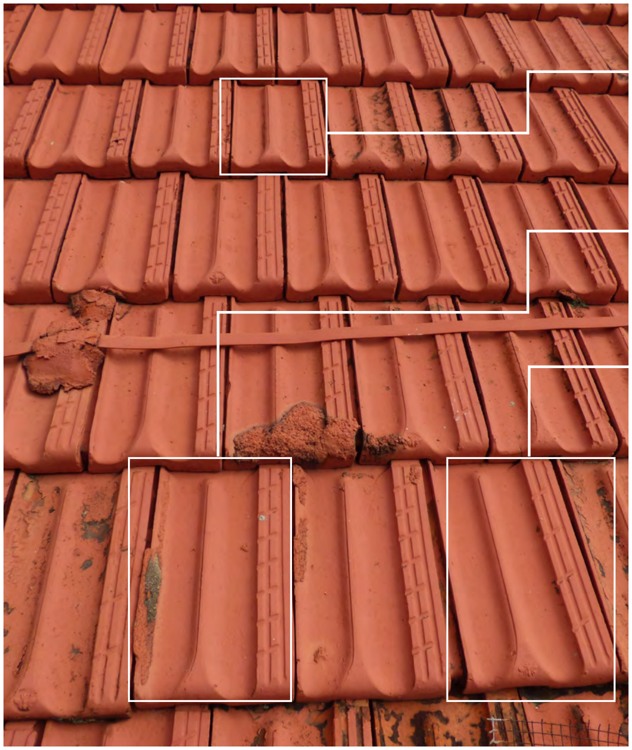
INTERLOCKING TILES

By the late 19th century, **Marseille tiles**, also commonly known as French tiles, were imported by agency houses into the Straits Settlements. These flat profiled terracotta tiles with interlocking grooves were developed in Marseilles in the 1850s. Guichard Carvin et Cie from Marseille St. Andre, France, was one of the manufacturers whose roof tiles were widely used here. The producers could be identified by their brand imprints on the underside of the tile. Marseille tiles of different fabricators were designed based on the same interlocking profile and dimension. Thus it is not uncommon to observe in historic clay tile roofs the co-existence of different brands, likely added through years of roof repairs.

Similar tiles made in India, especially Mangalore, were also imported here for its competitive pricing and were, referred to locally as **Indian tiles**. By the first quarter of the 20th century, **pantiles** with an S-shaped profile were also imported.



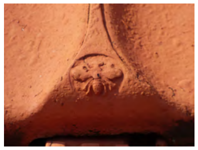
Variations of Marseille tiles:
Top: *Ventilator tiles allow warm air trapped in the roof space to escape, thus reducing heat build-up in the building interiors.*
Above: *Glass tiles serve as skylights introducing daylight into the building.*



Three different brands of Marseille found on the same roof plane, identified by the different imprinted brand logos.

Saccoman Freres St Henri - 5 stripes

Guichard Freres Seon St Henri - 7 stripes



Guichard Carvin et Cie St Andre - 4 stripes, with bee motif

Guichard Carvin et Cie St Andre - Ridge tile

1953 advertisement for Redland interlocking cement roof tiles. The featured Malcolm Road government quarters are still standing, some replete with Redland cement roof tiles.

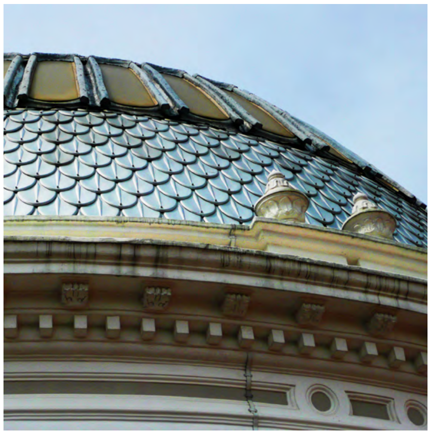
CEMENT ROOF TILES

Cement roof tiles, another variety of flat profile interlocking tile, were manufactured and sold in the Straits Settlements from the early 20th century. These tiles, made from Portland cement, and often containing fire-retardant asbestos fibers – now banned for its carcinogenic properties - were an economical, fire-proof and vermin-proof alternative to the imported Marseille tiles.

SHINGLES

Apart from tiles, another similar type of roof coverings used in Singapore that comes in small standardized units and produced in various materials, is shingles. Commonly used in the past, shingles likely did not gain traction due to relatively higher maintenance and reduced durability in this climate as compared to tile, metal, or concrete. Shingle roofs are now found only on the occasional heritage structure. For example, the Botanic Gardens bandstand features a flared timber shingle roof, while St Andrew's Cathedral is covered in slates (stone shingle), and the dome of the National Museum of Singapore was originally covered with zinc shingle – since replaced with aluminium ones.

Also refer to the following chapter on *Roof Covering: Metal*.



***Left:** Bandstand with timber shingle roof covering, Singapore Botanic Gardens. **Middle:** Gazebo at the MacRitchie Reservoir with slate roof covering (stone shingle). **Right:** Pressed metal shingle at National Museum of Singapore.*

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Vitrification is the partial fusion of clay in the tile firing process that affects porosity, the installation method and workmanship.

Common Deterioration

The condition and vulnerability of historic clay tiles depends on the quality of the clay, the degree of **vitrification**.

Well-made clay tiles, even historic ones, have a long lifespan often exceeding 50 years and even over 100 years. However poorly fired clay roof tiles are susceptible to erosion and disintegration of the clay body and are less tolerant of extraneous loading and stresses such as ad hoc works and movements.

Common defects of tiled roofs and causes are as follows:

CRACKING, BREAKAGE AND DISLOCATION

- Physical impact such as that caused by falling tree branches or maintenance workers walking on unprotected roof
- Stress caused by poorly done installation works such as for lightning tape, tile fastening systems, etc.
- Stress caused by shrinkage of inappropriate cement-rich mortar used for tile installation, or mortar deterioration
- Stress caused by roof structure movement, for example, due to building settlement
- Impact or stress caused by deterioration of the roof structure like battens, purlins or rafters

Roof tile breakage

SURFACE DAMAGE

- Long term exposure to the elements
- Inappropriate maintenance practice such as high pressure jet washing and sandblasting (as preparation work for inappropriate roof coating works)
- Dirt and moisture trapped by eroded surface giving rise to biological growth such as algae or plants, that worsens tile deterioration
- Superficial shrinkage of the glazed layer of glazed roof tiles leading to crazing

WATER PERMEATION AND EFFLORESCENCE

- Poorly fired tiles that are also badly weathered or impacted
- Efflorescence will accompany water permeation if clay body has salt contents

***Left:** Eroded tile surface and biological growth. **Right:** Efflorescence, or salt crystallization on roof tile – due to the clay tile body containing high salt content.*

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Diagnostics

Weathered ridge tile showing surface erosion, chipping, cracks and flaking.

VISUAL SURVEY

The tiles should first be visually inspected to ascertain visible issues and the extent of defects. Historic tiles are often found to be badly eroded and covered with thick layers of environmental soot. These should be cleaned by low pressure jet washing so that the extent of surface erosion can be better evaluated. Any surface coating will also need to be removed.

SAMPLE TESTS

Currently there is no standard test for assessing the condition of historic roof tiles. The common recommended approach is to collect sample tiles and subject these to standard tests meant for gauging the suitability of new tiles. However the tests and standards are designed to assess interlocking tiles and do not apply to V-profile tiles, which have different strength and material properties.

Samples should be taken from several locations to be sufficiently representative of the overall roof system (e.g. of different tile types, degrees of weather exposure, etc.). The tests include:

- **Transverse Strength (Breaking Load)** - by measuring the flexural strength of a set of tiles that has been removed from several areas of the roof, it is possible to determine whether they meet the minimum strength requirement.
- **Water Permeability** - this determines whether a tile is so porous that water can seep through it. Tiles are bonded to the bottom of frames that are then filled with water. The test is passed if no water drips from the bottom of the tile within 24 hours.
- **Water Absorption** - this determines the amount of water absorbed by the tiles after immersion in water for 24 hours.

In most cases, the old clay roof tiles would meet the requirements for transverse strength (breaking load) and permeability. However, the water absorption of most historic clay roof tiles frequently exceeds the maximum value recommended for current tiles, likely due to surface erosion.

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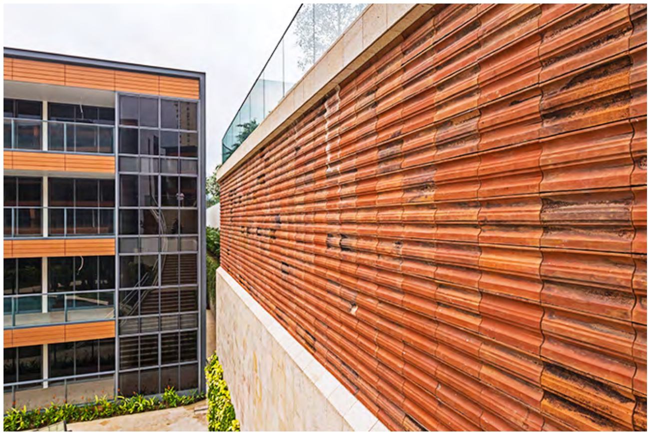
Also refer to Notes on Roof Conservation Works in *Chapter 1 Introduction*, and *Chapter 2 Roof Structures*.

Conservation and Intervention

Major restoration or repair works are usually called for only when there is aggravated deterioration from the lack of or inappropriate maintenance, historic tiles are poorly made or installed, and when historic tiles do not meet current day technical performance requirements.

Current-day roofing technical standards may differ from historic roofing systems and materials. Conservation advice should be sought should there be an intention to change extant detailing, such as adding new insulation layers. Design improvements may also be discreetly introduced especially at vulnerable spots to enhance roof performance, such as addition of flashing.

Where largely intact, the historic tile type and roofing system should be adhered to, so as to maintain the heritage and aesthetic character of the building. The exception would be asbestos roofing, which has been banned as a hazardous material, as well as poorly fired tiles that are porous and underperforming - these would have to be replaced. Such cases present an opportunity to introduce new roofing materials – however the historic roof structure, roof form, and height should be maintained for overall visual coherence of the historic architecture.



Left: *Corrugated metal deck as secondary roof receiving galvanised steel battens and Marseille tile finish, at the Victoria Concert Hall.* ***Right:*** *Salvaged historic Marseille roof tiles upcycled as landscape feature wall in the adaptive reuse development Sophia Hills.*

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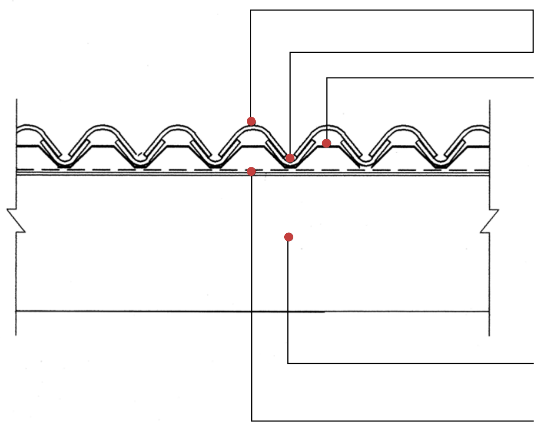
DISMANTLING / SALVAGING / RESTORATION

If the roof has to undergo major works such as structural repair, it would often necessitate the removal of tiles. Representative samples should be cleaned and tested for serviceability. If they are in good condition, the tiles can be retained. They should be carefully dismantled, cleaned, and any coatings removed, and reinstated after major roof repairs are completed.

In cases where water absorption test results are borderline, the tiles may be coated with water repellent to improve their performance. If the tiles fail the test – often due to historic clay tiles being inherently more porous than current products – they could be installed on top of a new secondary metal roof as a historic, but non-functional, roof finish, or replaced with matching tile type.

Replaced historic tiles could be salvaged and upcycled, for example, as a feature installation, wall cladding, or landscape pavers.

Detail drawing of V-profile tile cover laid onto secondary metal deck roof.



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Also refer to Notes on Roof Maintenance in *Chapter 1 Introduction*.

A useful starting point is the Sample Maintenance Checklist in *Volume 1 Resources*.

Maintenance

- Regular visual inspection should be carried out - general condition of the roof covering should be observed for signs of common deterioration, with special attention to the joints and mortars, i.e. along the ridges, flashing, etc.
- Timely maintenance and localised repair should be carried out using appropriate methods and materials before the defects worsen, such as realigning dislodged tiles, replacing damaged ones, mortar or flashing repair.
- Replacement, where necessary, is to be done with spare stock of the original tiles, or salvaged historic tiles of the same brand in good condition, or new tiles with the same dimensions and profile - to ensure proper installation and fit with existing tiles.
- A temporary cover should be installed to prevent further deterioration and water ingress into the building if a serious defect cannot be immediately addressed.

Deterioration and dislocation of v-profile tiles, disjointed roof timber members suffering from wet rot and structural risk – defects that should have been detected and addressed in their early stages by regular maintenance were instead left to worsen.

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- A prevalent maintenance malpractice is the application of paint, sealant or waterproof coatings on roof tiles to cover up weathering stains. In some cases, the tiles were chipped or sandblasted to prime their surfaces for receiving the new coatings, resulting in irreparable damage to a key heritage element.
- Roof tile covering should not be washed using high-pressure water jet – this will erode the tile surface and risk driving water into tile joints.
- Conventional cement rich mortar should not be used for repairing historic roof tiles that are of relatively weaker strength, resulting in stress-related damage.
- Mismatched and ill-fitting replacement tiles should not be used as this will lead to water ingress into the building.

***Top left:** Marseille tile roof inappropriately painted, likely to conceal signs of weathering and for a change in roof colour. **Top right:** Courtrai turquoise-glazed clay pantile imported from Belgium, glazing removed and tile body damaged by sandblasting, carried out as prep work for inappropriate maintenance paintwork.*
***Bottom left & right:** incompatible patching on roof tiles.*

4 ROOF COVERING: METAL

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Overview

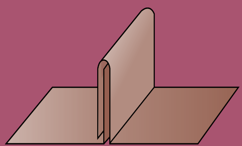
Metal was not commonly used in Singapore as a roofing material up until the early 1900s. The early examples featured metals with inherent corrosion-resistant properties, such as copper, zinc and lead, that oxidise with long term environmental exposure to create a thickened, protective coat of "patina". Although this property made such metals superior roofing materials, their relative high cost was prohibitive for common use in everyday buildings.

HAND-FORMED

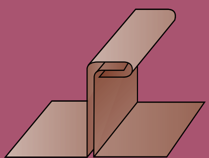
Copper, zinc and lead roofs were hence reserved for more prestigious buildings, and often limited to feature roofs and complex roof forms, such as domes, turrets and cupolas, whose shapes were impossible to achieve using conventional roof tiles. Historically, metal roof coverings took the form of shingles or smaller sheet tiles secured onto timber frames, such as the stamped zinc tiles on the dome of Raffles Library and Museum (1887, now National Museum of Singapore).

Maris Stella Chapel features an expressive roof composed of a few simple pitched roof planes with sheet metal roofing, constructed in situ with hand-crimped standing seams that are folded flat at the edges. A skylight is incorporated as part of the roof design.

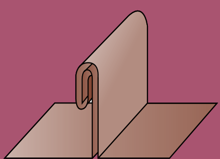
'Standing seam' refers to the method of joining metal sheets by crimping them together at the edges.



Standing seam



Single lock standing seam



Double lock standing seam

Right: *Timber substrate of copper sheet roof exposed during restoration at the Victoria Theatre and Concert Hall clocktower.* ***Far right:*** *A layer of fabric/ felt is found sandwiched between the copper sheet roofing and timber substrate.*

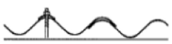
Alternatively, regular size metal roof sheets were laid over the timber substrate, often with an added layer of insulation fabric or felt in between, painstakingly worked by hand on site. Single- and double-lock seams are used to join the sheets and form the roof covering. In some cases there are no seams and the metal sheets are nailed directly onto the timber backing. At the Victoria Theatre and Concert Hall (1905), the dome roof atop the clock tower is built using small copper sheets wrapped around a 'barrel' substrate supported on timber ribs.

MACHINE-MADE

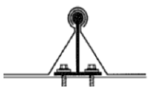
At the turn of the 19th century, the invention of metal-rolling machines, coupled with the discovery of the galvanization process, opened up the possibility of large scale and affordable application of zinc galvanised iron and steel roofing, without the previous problems of corrosion. Metal sheets could also be machine-rolled into corrugated profiles or stamped into pre-determined interlocking unit. Corrugated roofs were self-supporting and required less structural members underneath. Many of these roofing parts also came with galvanized bolts for easy installation without the need for on-site crafting of standing seam joints. This enabled a lightweight roof ensemble that could be pre-fabricated and quickly assembled on site, even for large roof areas. Although limited to simpler roof geometries, these manufactured metal roofs were popular for utilitarian industrial and ancillary buildings due to great reductions in time, labour and costs.

Simple and extended side laps for corrugated and trapezoidal profile sheets

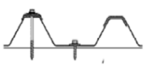
Supported side laps



Corrugated: fixed through crown



Concealed fix profile: no penetration of roofing sheet



Trapezoidal: fixed through trough or crown

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Patinated copper dome roof at the former Supreme Court.

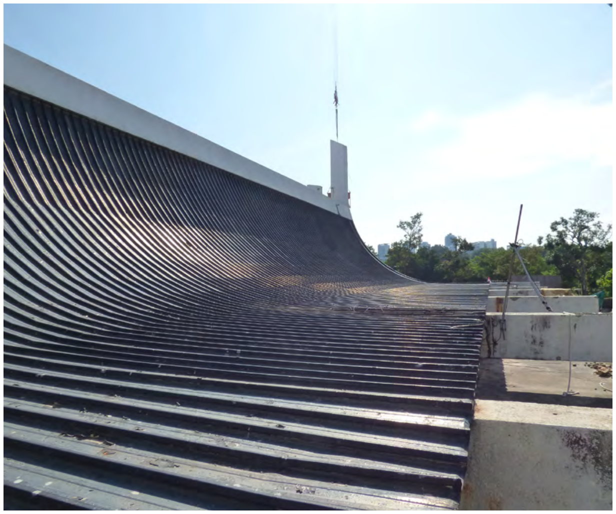
COPPER

The colour transformation of copper roof covering through its lifetime characterises this beautiful and long-lasting metal. From the initial colour of salmon-pink (immediately after production), it darkens to russet brown within days. Through years of exposure to oxygen, rain, carbon dioxide, environmental compounds of chlorine, sulphur and nitrogen, the gradual formation of oxides, carbonates, sulphates oxidative products, gives rise to a wide spectrum of blue- and green-hued patina. Being relatively more lightweight and easier to shape, copper is especially suited for high roofs, domes and cupolas, and also used for flashings on other types of roof coverings. However, it is also a more costly material.

ZINC GALVANISED IRON

Zinc is seldom used in its pure form but in the form of galvanized iron or steel sheets. 'Galvanization' refers to the process of coating by dipping iron into molten zinc, in order to prevent it from rusting. The process was first patented in Europe in 1836 and went into fullscale production by the mid-1800s, although pregalvanized products appear to only have been widely and commercially-available for buildings in Singapore in the early 1900s.

Zinc imparts anti-corrosion property to ferrous metal. This patina usually starts from dull silver grey and will turn into a soft, bluish/light grey over time. The patina is stable throughout its lifetime, an advantage over copper roof.



***Right:** Corrugated galvanised steel sheets used for a distinctive roof form with sweeping curve profile of the former Trinity Theological College Chapel (1960s). **Far right top:** Close-up view of galvanised steel. **Far right bottom:** Channels of the profiled sheet run from ridge to eave facilitating drainage, with the edge of the metal sheet folded down slightly as a drip detail at the eave.*

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Common Deterioration

Metal roofs are susceptible to damage caused by severe weather, ongoing **exposure to the elements**, poor **material considerations** or installation **workmanship issues** and **physical impact.**

- **Iron** and **its alloys** are prone to rust if not well protected. Unlike copper patination – which is a protective layer, iron oxide is damaging to the base material and detrimental to its functionality.
- Copper, although highly resistant, may also be corroded by sulphur compounds.
- **Corrugated zinc sheets and galvanised iron roofing** are not resistant to **acids** and strong **alkalis** such as that present in the atmosphere. **Cementitious residue** also corrodes zinc. Some zinc roofs may also be susceptible to a chalking, **'white rust'** effect.
- **Protective coatings** may wear off over time due to exposure to ultraviolet rays, rain and pollution.
- Deterioration of the **timber backing** due to **wet rot** caused by water ingress through the roof sheet or punctures, and **termite attack** are also common problems.
- **Rainwater run-off** can also cause uneven erosion of copper patina and streaking.

***Left:** Iron rust run-off on copper roof. **Middle:** Inconsistent erosion of patina layer and stain accummulation due to different exposure, run-off of water and effect of pollution. **Right:** Termite attack in the timber backing below the galvanised steel roof sheets and insulation felt/fabric.*

CORROSION

Corrosion is the major cause of deterioration for metal roofing – it refers to a range of complex reactions arising from exposure to atmosphere, heat, moisture, pressure and others.

- **Uniform corrosion** occurs evenly across the entire metal.
- **Pitting** is a type of localised attack appearing as small pits on the surface.
- **Stress corrosion** cracking occur when the metal is subjected to tension, bending etc. within a corrosion-inducing environment.
- **Erosion** occurs when the protective oxide layer is worn off exposing fresh metal to the corrosive agent.
- **Acid corrosion** is caused by acid rain or rainwater that has turned acidic upon reaction with biological growth such as algae and moss. Metal roofs, especially those of mild steel, galvanised steel, zinc, and copper, are particularly vulnerable.
- **Galvanic corrosion** is usually caused by differential metal reaction. Aside from the metal sheet, failure can also occur at connections including nails, rivets and bolts.

MECHANICAL FORCES

- **Abrasion** may result from impact of dirt, dust, sand, or grit just to name a few. Abrasion often results in removal of protective coating of the surface.
- **Fatigue** is gradual progressive failure as a result of repeated cyclic loading below the elastic limit. Inadequate provision for cyclic thermal expansion and contraction of metal sheets sometimes result in fatigue failure.
- **Creep**, on the other hand, is failure due to continuous sustained loading, especially under high temperature.
- **Punctures and tears** are caused by nails, bolts and restraints arising from movement and loads like wind or those caused by inappropriate maintenance activities.

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Also refer to Notes on Roof Conservation Works in *Chapter 1 Introduction*, and *Chapter 2 Roof Structures*.

Diagnostics

METAL IDENTIFICATION

Visual inspection is usually sufficient to assess defect types such as rust, discolouration, punctures, etc, and certain metal types such as exposed copper. However historic metal roofs are often found with multiple layers of inappropriate maintenance paintwork, concealing defects and the base metal type. It is critical to identify the base metal in order to carry out further diagnosis and repair.

- In the past, **spark test** was commonly conducted for metal identification. A high-speed grinder is lightly placed on the surface of the metal to create sparks. An experienced metal worker may be able to identify the metals by the length, colour and form of spark stream generated.
- Modern methods for metal identification include **X-Ray Fluorescence** (XRF) and **Optical Emission Spectrometry** (OES) - using X-ray and particular wavelength light respectively to identify the elemental composition of the metal type. Portable XRF enable limited identification of metal in-situ. More comprehensive XRF and OES are to be conducted in the laboratory.

Below: *Trial being carried out by specialist consultant for accelerated patination.* ***Bottom:*** *New copper roof sheet attached onto existing using copper pegs*

Conservation and Intervention

Specialist material consultants and tradesmen should be engaged to carry out metal roof repair and restoration, as it requires highly specialised skilled work and expert knowledge. For special roof forms, constructions, and restoration processes like artificial patination, such as for copper domes, mock-ups and trials should be carried out for each key step before applying to the entire roof.

MATERIAL

The original roofing metal, some with decades of accumulated patina, should be retained as much as possible, with localised replacement and patching only when repair work is insufficient. The same applies to the historic timber substrate.

Total replacement with a different material, for example expediently replacing historic zinc shingles with more corrosion-resistant and available aluminium, will result in loss of material authenticity and heritage significance.

Metals are susceptible to galvanic corrosion arising from dissimilar metals being in contact in the presence of moisture. As such aluminium, steel and galvanised fasteners must not be used on copper sheet. Run-off from copper roofing will also corrode aluminium and steel elements. Where patching repair or replacement is needed, similar materials must be used.

PAINT REMOVAL/RECOATING

One of the key metal roof restoration process involves removal of inappropriate coating using suitable chemical paint removers – and not sandblasting which will be too abrasive and damaging. Historically exposed material such as copper, and in some cases zinc, would be left revealed, while originally painted metal roofing such as steel would be primed and recoated using paint suited to the metal type.

REPAIRS AND REPLACEMENT

Minor corrosion damage on metal roof may be repaired by rust removal and anti-oxidation treatment. Minor cracks and tear may be welded, brazed or soldered. Larger areas may be cut off and replaced with similar material. In some cases there may be a need for design enhancement to correct past design flaws, such as for fixing details – this may then require replacement of the roofing sheets.

Left & middle: *Inappropriately painted copper pitch roof – before and after paint removal.* ***Right:*** *Deteriorated roof sheets were selectively replaced – photo shows timber strip used for manually forming the triangular profile standing seams.*

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Comparing colour and tonality of artificial patination trial panels.

COPPER: ARTIFICIAL PATINATION

A key conservation consideration is in matching the colour and tone of the new and historic metal roofing. While originally painted metal sheets only need to be matched for its coating, matching a patinated surface would require additional treatment. Artificial patination may be carried out on the new metal sheets using appropriate chemical treatment that accelerates the formation of patina, and even then it can take several months to form and stabilise.

The matching process has to be closely tailored according to where new metal sheets are introduced. For example, the existing patina of a historic copper dome roof varies widely in colour and tonality depending on the degree of exposure to solar radiation, wind, and rain, whether the spot is subject to any surface run-offs, and even the gradient (affecting the speed of drainage). The colours and tones are a result of varying chemical reactions between the metal and environmental factors. Replicating this process in artificial patination and gauging the match would necessitate trained hands and eyes.

ZINC AND GALVANISED IRON

The most practical way to repair damaged zinc sheets is replacement, as it is difficult to re-solder. Zinc rust may be treated with zinc oxide followed by a final coat of zinc-rich paint for originally painted roofing.

Rust on galvanized iron may be removed and the roofing sheet recoated with zinc through galvanizing processes (hot-dip galvanizing, electro galvanizing, sherardizing and metallic spraying). In corrugated galvanized iron sheets, there is tendency to rust around fixings, in the form of crevice corrosion. This may be repaired by inserting a slip-sheet with matching profiled corrugated sheets with provision for sufficient overlap and proper fastening.

__Right:__ Due to long term maintenance concerns, powder-coated steel sheet was used when replacing the badly deteriorated painted galvanised steel roofing at the Cathedral of Good Shepherd spire. Nonetheless it has the same base metal - iron. __Far right:__ In corrugated galvanised iron sheets, there is tendency to rust around fixings, in the form of crevice corrosion.

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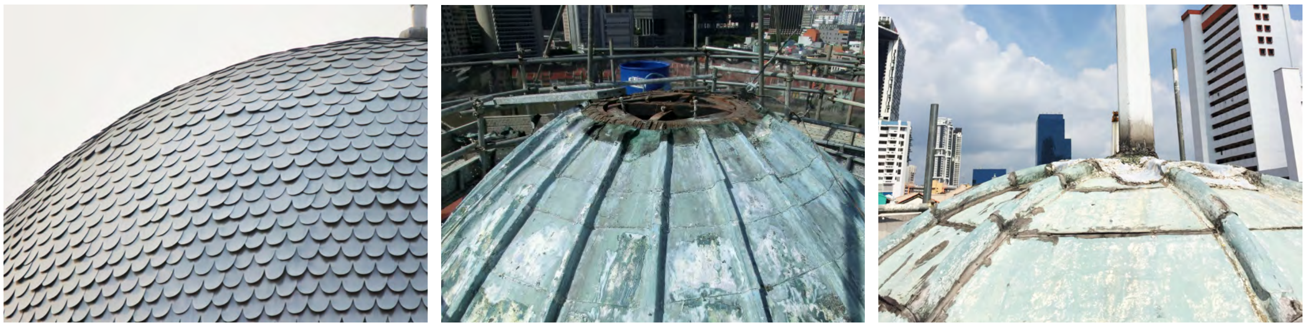
Also refer to Notes on Roof Maintenance in *Chapter 1 Introduction*.

A useful starting point is the Sample Maintenance Checklist in *Volume 1 Resources*.

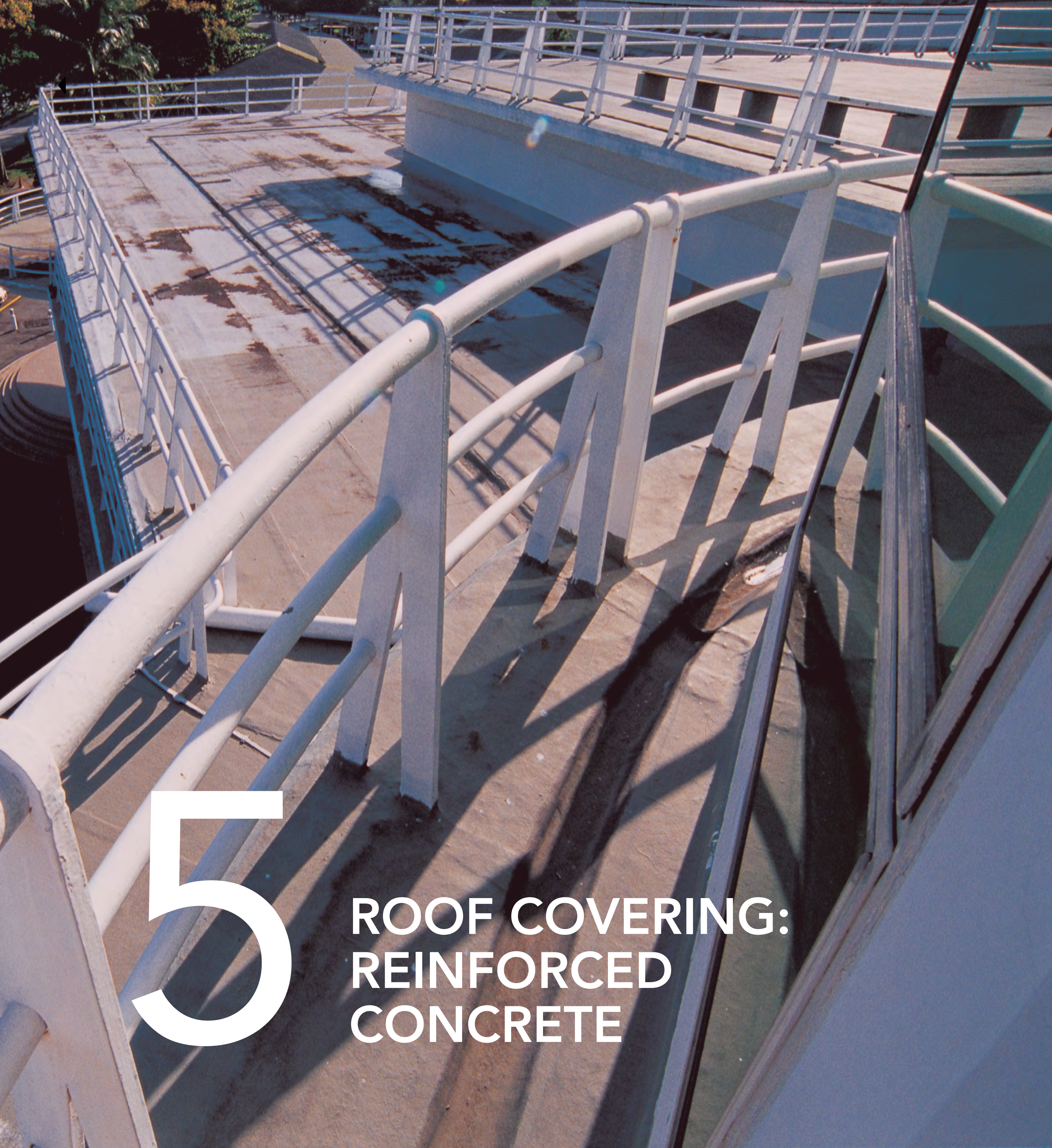
Maintenance

Sheet metal roofing will most likely last for up to 60 years, and potentially longer if well maintained. Its lifespan will be shortened by deterioration or corrosion, as well as galvanic corrosion. These are especially common in tropical climate with high moisture, radiation and heat.

- Conduct periodic inspection and maintenance at parts of the roof where debris and water are likely to collect.
- Special attention should be paid to the prevention of rusting, with periodic cleaning, rust removal and treatment.
- For historically painted metal surfaces, appropriate paint works should be applied as part of restoration or maintenance repairs to provide protection and inhibit rusting. Soft metal bristle wire brush can be used to remove surface rust after paint removal, before applying anti-rust primer prior to painting.
- Non-ferrous metals, such as copper, as well as historically unpainted metal roofing should not be coated or covered.
- Do not use inappropriate material and methods for maintenance repairs such as silicone sealants to address leakage.
- When carrying out maintenance inspection and localised repairs, avoid causing puncture and tear to the metal roofing.



Left: *Historically unpainted metal roof finishes should not be painted over, which drastically alter their character.*
Middle: *Inappropriately coated copper dome roof in the process of paint removal - greenish copper sheet could be seen.*
Right: *Inappropriate ad hoc repair using silicone sealant at the seams of copper roof sheets. Not intended for such use, the material breaks down after a short period, causing unsightly stains while the root cause of leakage is left unresolved.*



5 ROOF COVERING: REINFORCED CONCRETE

Overview


***Left:** Advertisement showing Chartered Bank with its RC dome roof, under construction in 1916. **Middle:** Kallang Aerodrome (1937) with generous flat roof decks where people could watch planes land or take off. **Right:** Expressive RC pointed vaults with clerestoreys incorporated at Nan Chiau High School (1965).*

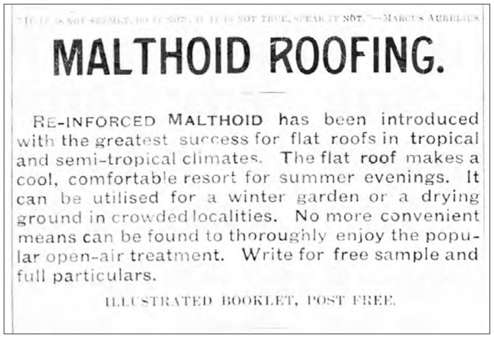
Introduced at the turn of the century for infrastructural works, modern reinforced concrete soon gained traction for building construction in the 1910s. An early example by French RC specialists Brossard & Mopin was the Chartered Bank (1916) at Raffles Place, built completely in RC, including its substantial dome roof.

While roofs with RC frames are often conventionally installed with battens and tile or metal roof cover, others may have cast RC slabs or vaults that span the supporting frame, doubling as both contiguous structure and roof cover, as can be found at Nan Chiau High School and Tanjong Pagar Railway Station. This has the advantage of being a seamless roof envelope, and in some cases, enabled accessible and usable 'flat roofs' to be constructed.

FLAT ROOF

Popularized in Singapore in the interwar years, flat roofs added an extra floor to the building - open-air decks where occupants and their guests could enjoy the evening breeze and views afforded by the elevated vantage point. They are typically built with an imperceptible ($<10^{\circ}$) slope for drainage.

RC ROOF BUILD-UP



MALTHOID ROOFING.

RE-INFORCED MALTHOID has been introduced with the greatest success for flat roofs in tropical and semi-tropical climates. The flat roof makes a cool, comfortable resort for summer evenings. It can be utilised for a winter garden or a drying ground in crowded localities. No more convenient means can be found to thoroughly enjoy the popular open-air treatment. Write for free sample and full particulars.

ILLUSTRATED BOOKLET, POST FREE.

1930 advertisement for "Malthoid" bituminous membrane, commonly used for waterproofing flat roofs in the past.

Concrete roofs are typically overlaid with a **waterproofing membrane** and finished with **protective screed** or other finishes. For example, flat roofs may also have **tile finishes**, commonly cement or ceramic tiles, as a watertight layer and aesthetic feature, especially for accessible roof terraces.

An early waterproofing product was the "**Malthoid**" **roofing sheet**. The water proofing membrane system may be concealed or exposed. Historic concrete roofs may also contain an **insulation layer** such as hollow cement blocks and terracotta tiles, for thermal insulation and for the latter, also fireproofing and water tightness.

Some historic buildings feature thin shell reinforced concrete roofs in the form of vaults, domes, parabolic arches and pitch roofs. These roofs may not have any waterproofing membrane and instead rely on rapid discharge of rainwater down the steep incline of the roof and finishes such as ceramic tiles to provide water tightness.

__Below:__ Bituminous waterproofing membrane (green finishing layer) on RC vaulted roof. __Bottom:__ Historic RC roof build-up revealed during partial demolition, showing terracotta tiles as an insulation layer.

Jellicoe Road warehouses (1920s) feature a series of thin shell RC pitch roofs with built-in gutter at the valleys.

Common Deterioration

BREAKDOWN OF BITUMINOUS WATERPROOFING MEMBRANE

Liquid applied bitumen is a common waterproofing layer found on local historic RC roof covers. The cohesion, or internal strength, and the flow properties of bitumen vary considerably with temperature and stress conditions. In the warm tropical environment, bitumen behaves as a liquid, highly susceptible to age and deterioration. Long-term exposure to the heat and sun causes photo-oxidation, a major deterioration mechanism that leads to hardening. The decrease in adhesive and flow properties results in lower tolerance to movements and impact, causing deformations and splitting, and paving the way for water ingress into the RC roof cover. Other contributing factors to bitumen hardening includes contact with water, dissolved compounds from atmospheric pollution, attack by microbiological organisms, and changes in its internal structure.

The topmost bituminous waterproofing membrane of the RC roof slab has badly deteriorated, revealing the underlying terracotta tile layer.

Water seepage stains and efflorescence at the undercroft of RC roof slab.

WATER SEEPAGE

- **Cause** - One of the main deterioration issues for concrete roofs is water seepage due to failure of the waterproofing membrane and/or the topping finishes. Many waterproofing membranes found on historic buildings were simply liquid applied bitumen that age and deteriorate easily (See Box). Deterioration such as cracks and debonding of other finishes like the topping screed and tiles can lead to water seeping into the concrete roof, especially for sloped roofs which often do not have waterproofing membranes.
- **Effect** - Water seepage in RC roof will cause leaching of soluble alkaline salts in the concrete, leading to formation of efflorescence (salt crystallization on surface) commonly encountered at the undercroft of the slab. Severe leaching will result in a concrete matrix with high porosity thereby further compromising the durability of the concrete. However, the greater implication of water seepage is corrosion of the steel reinforcement bars or steel deck permanent formwork.

Prolonged rainwater infiltration through compromised RC roof cover can result in complete carbonation of the concrete, resulting in extensive corrosion of rebars and concrete spalling.

CARBONATION

- **Cause & Mechanism** - In modern RC, the highly alkaline concrete cover ensures that the embedded reinforcement steel is protected by a passivating oxide layer – that also aids in bonding the steel and concrete. Carbonation is a process where this alkalinity is reduced when carbon dioxide in the atmosphere reacts with calcium hydroxide and moisture in the concrete. Reduced alkalinity leads to breaking down of the passivation layer, leaving the exposed steel vulnerable to corrosion especially in the presence of moisture. Carbonation starts at the exposed concrete surface and propogates inwards. When it reaches the steel reinforcement, the altered concrete is no longer protecting the steel from corrosion.
- **Effect** - Corrosion of the steel is accompanied by expansion of the metal. This change in volume results in expansive forces which then cause cracking and spalling of the concrete surrounding the steel.

OTHER AGGRAVATING FACTORS

- Water seepage, carbonation and corrosion of the steel can be aggravated by the presence of cracks in the concrete roof. The cracks can be caused by shrinkage, movement due to moisture and thermal changes, loading or structural distress.
- A breach in the roof watertightness can also occur due to defects in other roof features such as parapet walls.
- Other problems encountered in historic concrete include poor compaction when casting during construction.
- Poor concrete composition mix including the use of inappropriate materials, such as sea sand containing chloride or reactive aggregates, can accelerate the rate of corrosion of the steel.

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Diagnostics

DESKTOP STUDY

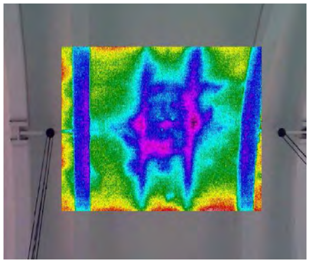
It is important to establish the historic construction build-up and details of the roof, for instance presence of waterproofing membrane, original and latter-day membrane types, drainage paths, types and construction of topping finishes, gradient, termination details, the condition and detail of any penetration. This may be done through studying past records, archival research of old drawings, site investigation, non-destructive tests, and sampling and analysis.

Example of mapping of cracks (red lines) of the RC roof slab undercroft.

VISUAL SURVEY

Documentation of the extent of damage should include detailed photography and mapping. The underside of the roof should be inspected where visible, as well as the ceiling, where water seepage stains may indicate roof leakage. In assessing the condition of the historic concrete roof, the following aspects should be included:

- Identify all sources of water seepage especially around terminations and penetrations.
- Mapping of the following defects:
  - Efflorescence
  - Concrete spalling (usually at roof undercroft)
  - Cracks - including the types of cracks, crack width and associated signs like rust stain
  - Plant growth, including around the parapet walls and edges of roofs
  - Deterioration of topping finishes such as the presence of cracks, debonding, spalling
  - Deterioration of water proofing membrane where visible



Infrared thermograph of the undercroft of an RC vault roof shows water seepage. Materials with lower heat retention manifest as cooler shades, such as the two RC elements with metal rebars on both sides, and the waterlogged area at the centre of the roof slab.

NON-DESTRUCTIVE TESTS

It will often be necessary to trace for concealed sources of water seepage or trapped moisture in the roof slab, to establish the extent and method of restoration and repair required. These call for specialised techniques that require skilled operators, equipment, and expertise interpretation. Non-destructive techniques for tracing concealed moisture include:

- **Infrared Thermography**
- **Moisture Tomography** using microwave or capacitance method
- **Surface Penetrating Radar**

The extent of corrosion of the steel reinforcement and damage to the concrete can then be detected using a series of non-destructive tests to measure the following indicators that will show the corrosion activity, risks of corrosion activity and corrosion rate:

- **Depth of Carbonation**
- **Half-Cell Potential**
- **Concrete Resistivity**
- **Linear Polarisation**

SAMPLING

It may at times be necessary to determine the composition and condition of the concrete before any intervention measures can be derived. This would require extraction of concrete core samples, broken fragments and powder for the following tests:

- **Petrographic Examination** to determine the condition of the concrete such as porosity, secondary reaction, cracks and general quality including composition like types of aggregates and cement
- **Salt Analysis** of chloride and sulphate content

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Conservation and Intervention

Also refer to Notes on Roof Conservation Works in *Chapter 1 Introduction*

DESIGN ENHANCEMENT

The builders and designers of some early flat roofs have not catered sufficiently for the tropical climate thermal heat gain, resulting in overly warm interiors. Particularly for residential buildings, it may be necessary to introduce a secondary roof over the RC roof to improve thermal comfort.

The top floor units of early public housing flats with RC flat roof experience high heat gain.

MATERIALS AND METHODS

Materials and methods for restoring RC roof cover should be sympathetic to the existing concrete. As most historic concrete would be of lower strength than current standards, the repair materials such as the mortar or grout should be carefully selected to be compatible with the historic substrate and to address the specific type of repair required. Conventional repair materials tend to have high compressive strength and are impermeable, and may not be appropriate for use in repairing low strength historic concrete with lower elastic modulus. The properties of the historic concrete needs to be fully determined through testing, and the proposed repair materials verified via laboratory analysis, trials and mock-ups.

Applying finishing screed to restored thin shell RC vaulted canopy. The original roofing did not have a waterproofing layer, and adding one would have changed the thin-shell roof aesthetics – instead a waterproofing additive was added to the finishing screed.

WATERTIGHTNESS

The primary aim of concrete roof restoration is to address all water seepages and restore watertightness. This often involves the treatment of all cracks on the concrete roof and surrounding features like the parapet wall and re-laying of new waterproofing membrane. This may entail removal of the existing finish layer and any underlying waterproofing membrane. Alternatively, a new exposed membrane can be applied over the finish layer. In this case, the finish layer needs to be of sound condition, undergo proper surface preparation and cleaning, before receiving the new membrane.

If the roof is originally finished with historic tiles, it should not be overlaid with exposed waterproofing membrane. Rather the tiles should be carefully removed to lay the new membrane, before reinstating the historic tiles. Where this is not possible, alternative methods of treating the roof should be explored which may include injection, repointing of the tile joints, application of impregnating water repeller over the tiled layer and improving the drainage of the roof.

CRACKS AND SPALLING

Cracks in the concrete elements can be injected with epoxy. Spalled concrete due to **corrosion of reinforcement bars** will need to be repaired by **removing the rust** from the steel, and priming it with **anti-rust coating** before patching with **compatible mortar**.

Concrete rehabilitation by integration repair—white patches of fiber-reinforced mortar applied on badly spalled RC roof slab to return strength and integrity to the concrete cover.

Repair of RC roof concrete spalling – removal of deteriorated concrete and rust, replacement of rebar if necessary, treat with anti-rust coating, and patching with compatible mortar.

CARBONATION AND REBAR CORROSION

Ongoing corrosion activity of the steel bars in concrete which have not cause spalling, such as that induced by water seepage and loss of passivation due to carbonation, may be addressed by applying protection systems. The following systems are non-destructive and no concrete layer needs to be removed. However, these will need to be carried out by specialist applicators:

- **Coatings and sealers** - Provision of film-forming coatings and penetrating sealers. It is important to note however that film-forming coatings are often inappropriate for use on historic concrete unless the structure was originally coated. Impregnating sealers render fine cracks and pores within the concrete hydrophobic but they do not bridge or fill the cracks. Once applied, these sealers will require periodic re-applications. Anti-carbonation paint can be applied to arrest future carbonation or the concrete cover may be increased for additional protection but only where it does not alter any important historic features of the concrete.

- **Cathodic protection** - Corrosion is an electrochemical process in which electrons flow between cathodic (positively charged) and anodic (negatively charged) areas on a metal surface, with corrosion occurring at the latter. Steel corrosion can thus be arrested by generating an electrochemical process with the metal surface acting as the cathode.

- **Re-alkalisation** - This is a process to restore the alkalinity of carbonated concrete by soaking the concrete with alkaline solution. In some cases the alkaline solution is forced into the concrete to reach the steel bars via the passage of a direct current.

- **Topical migrating corrosion inhibitor** - The corrosion inhibitor once applied onto the surface of the concrete will migrate to the reinforcement first by capillary suction and then by diffusion (both liquid and vapour). The inhibitors then create a protective layer on the entire reinforcement surface on the basis of mixed corrosion inhibiting effect. This means that the corrosion will diminish on the anodic sites of the reinforcement whereas on the potential cathodic sites the inhibitors will prevent oxygen from reaching the steel.

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Refer also to *'Notes on maintenance'* in the Introduction chapter

A useful starting point is the Sample Maintenance Checklist in *Volume 1 Resources*

Maintenance

In general, up-to-date records of construction and inspection documents should be obtained and accessible - this will inform any future restoration works and ensure the appropriateness of past repairs. Full specialist inspections should be conducted at regular intervals typically every five years, while regular visual checks should be conducted every three months, especially for flat roofs.

Protective coating and waterproof membrane applied in previous restorative efforts should be well documented; this is to aid the scheduling of any renewal of protective coating and replacement of waterproofing membrane.

Tile-finished concrete roof covers are durable roofing system and should have minimal maintenance issues if properly and carefully laid. Nevertheless, their maintenance is important in order to avoid major problems. Keeping them in good condition is also important as it helps preserve the colour and design of the tiles.

MINOR REPAIRS

The roof should be inspected for blisters and cracks, which will cause water to seep into interiors. Simple repairs such as grouting with low-shrinkage cement can be possible with smaller cracks. However, treating larger cracks would require the advice of a concrete roof specialist. The condition of sealants between pre-cast units and joints should also be checked during regular inspections and localised repair done where needed.

Exposed waterproofing membrane with blistering and other defects should be replaced.

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CLEANING

Due to the design, concrete flat roofs are prone to accumulation of dirt and debris and the related issue of ponding, as well as moisture-induced moss and lichen growth.

Washing to remove debris and growth can be carried out using controlled pressure blasters with lower pressure and a concrete rating nozzle as this method is less damaging to the concrete and minimizes moisture being driven into the substrate. The water should be directed from the highest part of the roof in the general direction of the drainage fall.

Left: *Plant growth on RC roof canopy where the drainage holes are located suggests that there is chokage – any debris should be cleaned, and vegetation growth carefully removed and treated with herbicide.* ***Right:*** *Accumulation of dirt, debris and plant growth at the drainage holes of an under-maintained flat roof.*

6 CEILINGS AND SOFFITS

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Overview

Right: *Capitol Theatre is famed for its massive ornamented ceiling that featured precast elements in a stylised reed bunch design, with cornices made of in-situ render on lath.* ***Far right:*** *timber strip eave soffit with decorative fretwork that also serve as vents, at a Koon Seng Road townhouse.*

A ceiling is the overhead plane or surface of an interior space. In this chapter, the focus shall be on false ceilings – a secondary ceiling layer suspended from the structural element above. Traditionally, false ceilings serve a similar architectural function as internal wall linings in concealing floor and roof structural members, as well as plumbing and electrical wiring.

Soffits can be seen as an extension of false ceilings, but located on the building exterior at the underside of eaves, concealing rafter ends and the underside of roof covering. In local heritage buildings with soffits, these are predominantly constructed of plasterboards.

Ceilings under roofs, and soffits, enclose the roof space and form the 'bottom plane' of the roof system. Given the limited accessibility of most roofs, problems are often first detected at the more visible ceiling or soffit, for example, as stains from leakage or rusting steel roof members.

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***Top:** Timber board eave soffit with a ventilation panel. **Above:** Exposed timber ceiling joists on which the timber strip ceiling (as seen on the left) was secured.*

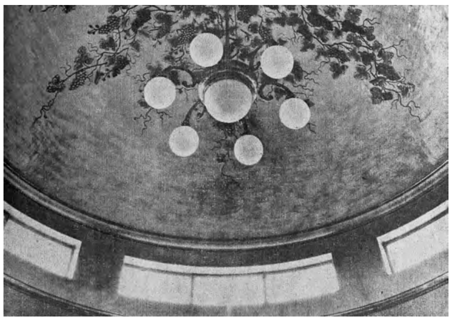
Ceiling / soffit panels or tiles are typically installed by fixing them to timber joists or metal frames suspended from floor or roof structure. Moulded ornamental plasterworks on the other hand are formed by applying the lime based plaster in layers onto steel mesh or chicken wires that have been secured or anchored to supporting structures such as roof beams.

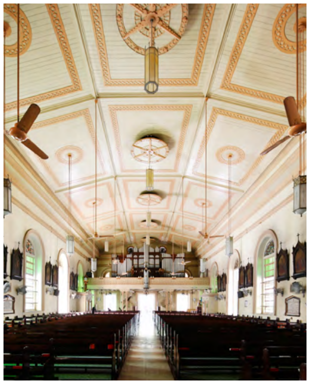
The air space between the roof and the suspended ceiling also plays an important acoustic and thermal insulation function. 'Ventilated' ceilings and soffits can be found in historic buildings where integrated vents, usually in the form of louvred or perforated panels, work together with jack roofs, dormers, roof vent tiles etc. to allow air circulation in the roof space as a passive climatic control strategy in optimising interior comfort.

PLASTER

The earliest and most common ceilings and soffits in the local context are made of lime plaster, rendered onto a stiff timber-framed or metal lath substrate. Such plaster panels are highly adaptable to the geometry of the rooms as well as roof profile, given its in-situ composite build-up. Ceiling works became a specialised trade that required carpentry skill for the construction of the backing material, and plastering expertise to ensure that the finish is level and smooth, working against the pull of gravity. Prefabricated plaster ceiling panels became available later on with semi-mechanised production. These usually came in ready-made flat units of various dimensions, made of lime plaster reinforced with fibre of plant origins (and later, asbestos fibres), poured, mixed and set in wood or metal moulds. Proprietary products such as the 'Celotex' acoustic ceiling were used in government buildings such as the Municipal Building (later City Hall, and present-day National Gallery).

***Right:** The epitome of such craft is seen in the legendary gilded and frescoed domed plaster ceilings of the 1937 Haw Par Villa, which used up the entire stock of gold leaf in the colony at that time. **Far right:** Ornamented plaster ceiling in the former Chief Justice Chambers, old Supreme Court (National Gallery)*





***Top:** Timber strip ceiling overlaid with decorative fretwork at the Cathedral of Good Shepherd. The centre row of dropped circular ceiling panels allows for the escape of rising warm air through the roof space and jack roof above. **Top right:** Teak coffered ceilings convey a sense of formality and understated opulence in an otherwise restrained, monochromatic material palette at the former Supreme Court.*

TIMBER

The original simple plastered ceiling of the Cathedral of the Good Shepherd gave way to an elaborate timber strip ceiling in the 1910s, when it underwent re-roofing works. The use of timber for ceilings are, not surprisingly, reserved for buildings of stature – due to its much higher material and labour cost. Given their heft compared to plaster ceilings, timber ceilings also require the use of heavy gauge timber, or mild steel framing. The Cathedral timber ceiling incorporated a row of dropped panels, allowing hot air to move through the roof space and escape via louvred openings of the jacked roof above the ceiling.

An ornamental variation requiring fine carpentry work is the timber coffered ceiling. An elaborate example can be found in the former Supreme Court (now National Gallery of Singapore), made of Burmese Golden Teak, lending dignity, prestige, and the right acoustic resonance to the 'Salle de Perdu' and the courtrooms.

1935 newspaper advertisement for stamped metal ceilings imported from Australia.

METAL

Products of industrialisation, stamped or pressed metal panels or tiles started out as affordable alternatives to hand-rendered ornamented plaster ceilings, wall dadoes and cornices. Originally stamped from steel, the panels were later plated with tin to slow down rusting, giving rise to the term "tin ceiling". Mass produced sheets of thin rolled tinplate in a myriad of patterns and panel sizes were very popular from the 1890s to 1930s, especially in America and Australia. These were either painted to simulate ornamental plaster, or left in metal finish. Marketed for their fire- and vermin-proof properties, they were imported to Singapore by trading houses. As early as 1891, the Church of St Peter and St Paul had replaced their plaster ceiling with pressed metal panels from Ohio, a major metal ceiling production hub in America.

However, due to the warm and humid climate, difficulties of maintaining elements at height and lack of restoration knowledge, most local examples unfortunately suffered from extensive corrosion over the years. Those in St Peter & St Paul's were completely replaced in the recent round of refurbishment works.

__Right:__ Ornamental ventilation unit as part of the metal ceiling system of the chapel at the former St Joseph's Institution (1912, presently Singapore Art Museum). __Far right:__ One rare surviving example in a bungalow (1925) at 126 St Patrick's Road (present-day clubhouse).

__Top:__ Dislodged soffit plasterboard panel. __Above:__ If ceiling water ingress is left untreated, the damage may worsen to paint peeling, staining, timber joist wet rot, termite infestation, and may even affect adjacent structures or elements.

Common Deterioration

CONDENSATION, WATER INGRESS

Prior to the prevalence of air-conditioning, historic buildings were mostly designed for effective ventilation, ensuring a comfortable and airy interior environment. Moisture evaporated easily with good air circulation, lowering the likelihood for ceiling or soffit deterioration.

However, with the introduction of airconditioning to an increasing number of historic buildings, ceiling condensation has become a significant problem. Hot and humid air tends to be trapped in the roof space above the ceiling. Condensation then occurs on the topside of the ceiling, which is cooled by the air-conditioning in the room below.

When there is direct water ingress from a leaked roof or punctured facade into the roof space, water tends to collect on the ceiling or soffit panels. Similar to condensation, the gradual moisture build-up will lead to irreversible damages, which include staining, metal corrosion, rotting of timber panel and joists, deformation and deterioration of different materials.

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Right: *Incompatible patching of ornamental ceiling. Panel dismantled to reveal termite infested ceiling joist.* ***Middle:*** *Badly deformed metal ceiling panel.* ***Far right:*** *the thick paint layers are peeling, exposing the severely corroded metal beneath.*

DEGRADATION OF PROTECTIVE COATING

Degradation of paintwork or any protective coating on the ceiling surface (for example, paint peeling) resulting in exposure of the base material could accelerate any deterioration.

If the ceiling or soffit damages are left untreated for a long period of time, the aggravation of defects could lead to serious safety concerns for the building users. These elements may bulge, crack, split, breakdown, and even detach from its supports and cause accidents.

Diagnostics

Ceiling inspection using elevated access equipment to reach high areas.

VISUAL AND TACTILE SURVEY

- Check for visible signs of defect – watermarks or patches of dampness, cracks, bulges, detachment, rots, corrosion stains and any deformation.
- Establish and document installation details such as the support system, if not already known.
- Check integrity of ceiling or soffit – for example if the panels/tiles are firmly secured. Movement of the building can result in dislodgement of elements that can manifest as gaps or loose panels.
- Check for corrosion of metal lath backing and fixing nails from prolonged moisture contact.
- Carry out probe or knock test to detect debonded plasterwork or hollowed out timber members.
- Check for signs of termite activities on plaster and timber elements.
- Videoprobe or borescope can be used to inspect inaccessible corners above the ceiling or soffit.
- Localised removal of paint may be useful to assess the condition of metal ceiling panels.

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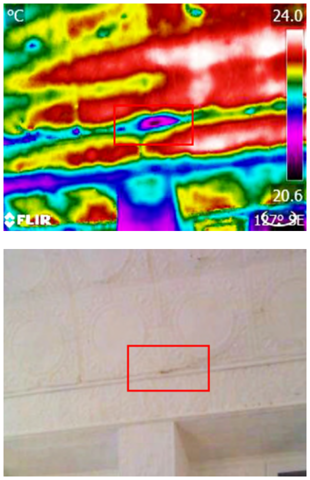
NON-DESTRUCTIVE TESTS

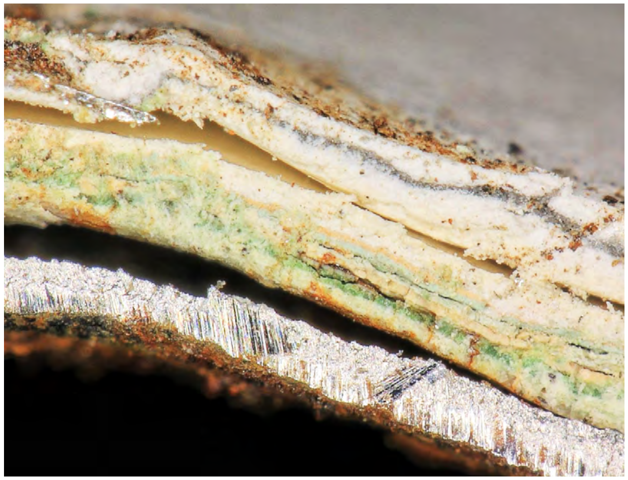
- **Infrared Thermography** to locate problem areas of water seepage, wet rot, cracks and detachment from supports.
- **Timber Resistograph** to assess the extent of damage for timber elements such as ceiling panels, supporting joists.
- **Radar and Vibration Sensors, Carbon Dioxide Detector or Infrared Thermography** to detect active termite in timber elements.
- **X-Ray Fluorescence Spectroscopy (XRF)** to identify type of metal for metal ceiling panels, measure thickness of coating layer and metal beneath (especially if corroded)

SAMPLING AND ANALYSIS

- **Chemical Analysis** to identify type of timber and composition of plaster panel or moulded plasterwork.
- **Metallurgy and Petrography** to microscopic examination of metal and plaster elements respectively, to assess the deterioration mechanism, defect extent and material composition.
- Where suspected, plaster ceilings or soffits should be tested for asbestos content.



Infrared thermograph of ceiling area – blue and purple areas are 'colder', denoting moisture, likely due to condensation on the metal panels, coinciding with corrosion stains.



Microscopic study of metal ceiling sample allows for accurate measurement of the ceiling thickness, and paint seriation to derive the original ceiling colour scheme. It could also be seen that the adhesion of paint to metal is poor, and that the ceiling underside has rusted.

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Conservation and Intervention

***Right:** The elaborate precast ceiling ornaments of the Capitol Theatre have been painstakingly restored, while the badly deteriorated plaster on lath trim had to be replaced with new material that matched the existing design. **Far right:** Installation of replica timber strip ceiling to replace the deteriorated sections.*

Though differing in materials, the overall steps in the conservation and repairs to historic ceilings and soffits are similar:

- Removal of existing finishes to bare substrate in order to carry out a detailed inspection of the underlying condition.
- Document and classify the defects in terms of nature, severity and extent so as to formulate strategies for conservation, partial or complete replacement.
- Carry out localised repair works to reinstate the integrity of the ceiling element and supporting structure (where access is available). Such repairs are usually done in-situ to minimise damage.
- However, in some cases it may be necessary to dismantle and restore off-site, such as major renovation works that may inflict damage. A detailed study and condition survey of the fixing method and support frame above would need to be carried out to inform an appropriate method and sequence of dismantling, restoration, and reinstallation work.
- Application of protective treatment to both retained elements and replacements – in the case of timber, preservative and anti-termite coating, and for metal, a zinc-rich primer would be necessary.
- Application of new finishing, be it paintwork or varnish. Depending on the degree of intervention (e.g., adaptive reuse or preservation) and their existing condition, plain plaster ceiling or soffit panels at the end of their serviceable lifespan are usually replaced by new replicas. This applies especially for plasterboards that tested positive for asbestos – specialist contractors have to be engaged for the dismantling, removal, disposal of ceiling, and site decontamination.

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Trial for paint removal of ornamental metal ceiling panel.

On the other hand, ornamental plasterwork, timber and metal ceilings with more elaborate design and quality materials would be prioritised for retention and conservation.

It is much more challenging to restore stamped metal ceilings in the local context due to their extremely fragile nature and usually poor condition. It is critical to first stabilize and consolidate the surface as preparatory works that precede the actual conservation and repair work. A new substrate would need to be designed and installed to reinstate the integrity of the ceiling.

Maintenance

Also refer to Notes on Roof Maintenance in *Chapter 1 Introduction.*

Roof space above ceiling should be inspected as part of regular maintenance schedule.

- Periodic visual checks on the watertightness of the building envelope and the roof should be carried out to ensure that there is no water ingress. There may also be concealed plumbing or drainage piping within concrete slabs or roof spaces. These should be periodically inspected for signs of water seepage due to malfunctioning or chokage of piping that may affect ceilings and soffits.
- Non-destructive scanning by infrared thermography may be employed once in a while to detect water seepage, especially for concrete slabs.
- The interiors and roof space would need to be well ventilated and kept dry. This is especially important for timber and metal ceilings. Relative humidity and temperature monitors can be installed for historically and aesthetically significant feature ceilings.
- For metal ceilings in air-conditioned spaces, care needs to be taken to detect signs of condensation that may cause corrosion of these elements. It is recommended that the M&E design of the interior and roof space take into account and minimise condensation risk.
- It is crucial to undertake regular maintenance checks even for high level ceilings and soffits that may require elevated access, especially if these are significant building features.

7 ROOF ACCESSORIES AND ORNAMENTS

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Overview

For maintenance repairs of roof stuccowork such as gopuram figurines, or precast concrete ornaments such as finials, please refer to Volume 3 Facades, *Chapter 2 Plasterwork* and *Chapter 8 Precast Concrete* respectively.

Common historic roof accessories found here include rainwater goods such as gutters, hoppers and downpipes, as well as fascia boards - wide strips capping the ends of roof rafters, trusses or beams along the eaves that may also serve to close the gap between the roof covering and soffit. Gutters are often supported off fascia boards running horizontally along the lowest edge of the roof fall. These functional elements may be plain and simple in design or they could also serve as part of roof ornamentation adding visual interest to the building exterior.

Other roof ornaments may be less functional in the practical sense, though as part of the building visage, they may serve symbolic roles in signalling to the public the purpose of the building or the social status, wealth, taste, cultural affinity or desired brand image of its owner and occupants. These include ridge or eave ornaments, stuccowork, finials, flag posts, crucifixes on churches, and Chinese ceramic shardwork. The main broad categories are covered below, along with their respective deterioration issues and conservation approaches.

Left: *A rare example of moulded roof eave ornament at the Chinese-influenced former Anglo-Chinese School Cairnhill Road campus, a reinterpretation of the Chinese yanshou (eave charms), in the form of a grotesque.* ***Middle:*** *Stucco figurine on the Sri Mariamman Temple gopuram (entrance tower gate, first built 1930s, redecorated 1960s).* ***Right:*** *Malabar Mosque (1956) featuring onion-shaped domes topped with finials, reflecting the moghul influence that was introduced and popularised by the British colonials.*

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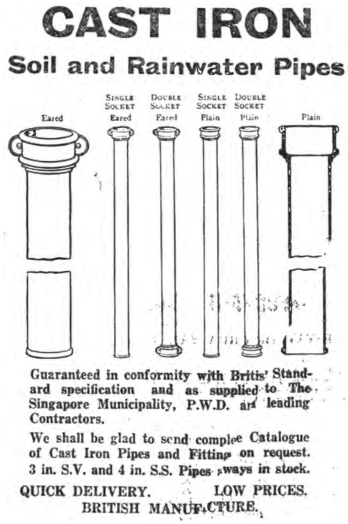
Rainwater Goods

__Right:__ Cast-iron rainwater head or hopper incorporated as a building ornament. __Far right:__ 1929 newspaper advertisement for cast-iron rainwater pipes.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BRITISH MANUF CTURE.

Pitched roofs are often central to building traditions that have evolved in regions with high rainfall, to ensure water is thrown off and drained away from the building. Drip details such as pointed eave tiles, and grooves on the underside of sills, serve to prevent backflow, breaking up sheeting rain into controlled drips with reduced impact on the building facades.

The incorporation of regularly-placed gutters and pipes as a building system for an even more efficient and controlled rainwater discharge is a relatively recent concept, enabled by industrial mass production of affordable rainwater goods. Gutters run along the building eaves and roof valleys, draining into hoppers or heads that lead to downpipes installed on facades.

By the 1920s, most buildings in Singapore were outfitted with gutters and downpipes. The most common types were made of **cast-iron** or **galvanized iron (GI)**, produced in Scottish foundries as prefabricated segments, marketed via sales catalogue, shipped, and assembled quickly on site. Later on, rainwater goods became available in mild-steel. A major manufacturer that supplied to Singapore was Walter Macfarlane & Co. in Glasgow. Due to their robust material, where maintained properly, most historic rainwater goods are found to be intact and still in serviceable condition.

Cast-iron is made by pouring molten iron into a mould. Since the mould could be reused multiple times, cast-iron pieces could be consistently and economically-produced.

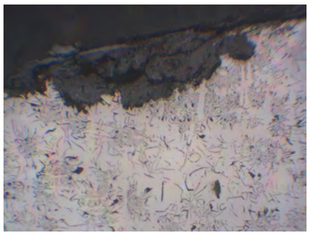
Top: Gutter choked by dead leaves despite having been installed with a wire mesh cover, leading to plant growth. ***Above:*** *Paint peeling and badly corroded bracket securing downpipe to wall.*

DETERIORATION AND DIAGNOSTICS

Visual Survey

Regular visual inspections should focus on the early signs of deterioration. For example, plant growth or ponding may be signs of chokage, and may lead to moisture-related corrosion.

- Biological growth
- Chokage or ponding
- Dislodged components and defective brackets
- Cracks - cast iron is brittle and can break or fracture due to building movement (e.g., caused by soil settlement) - especially where brackets secure the components to the building.
- Leakage
- Rust stains, especially around brackets and joints
- Paint failure
- Corrosion
    - Crevice corrosion is commonly found around the joints of two component segments or the brackets, where water is easily trapped.
    - Pitting corrosion has also been found in cast iron embedded within walls, leading to leakage into the buildings.



Microstructure study of gray cast iron from rainwater downpipe sample.

Non-Destructive Tests and Sampling

- The original or remaining thickness of cast iron pipes can be estimated using an ultrasonic thickness gauge. The results will show the corrosion extent and is best measured after removal of all layers of paintwork.
- The downpipe interior can be inspected with the aid of a videoprobe.
- For restoration purpose, it may be necessary to verify the type of cast iron - whether it is gray, ductile or other types of iron. Grey cast iron has better corrosion resistance than steel. However it is still susceptible to corrosion, especially in humid and acidic environment. Similar to metal roofs, this can be carried out using in-situ metallurgical examination, or the removal of a small sample for off-site assessment.

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Also refer to Notes on Roof Maintenance in *Chapter 1 Introduction.*

Rainwater goods that are an integral part of the historic building design may be retained and restored as heritage elements even if they no longer perform the main drainage function.

Dismantled rainwater downpipe prior to off-site restoration.

CONSERVATION, INTERVENTION AND MAINTENANCE

Conservation Approaches

Current regulations have disallowed the installation of exposed gutters, due to the general lack of maintenance that often lead to these becoming conducive mosquito breeding grounds. In some cases, the historic drainage system may not have sufficient capacity. For historic buildings with existing rainwater goods of heritage value, there are two broad approaches.

If there are no significant drainage issues, the gutters and downpipes could be restored and reinstated, but sealed up, as non-functioning heritage elements in their original locations. Sometimes the gutters are dismantled, leaving only the more visible downpipes. They could also be dismantled completely and only selectively kept as heritage displays elsewhere.

When drainage is still required, a special case may be made for the historic rainwater goods to be retained as a functioning system. If additional capacity is needed, a solution is to install a new concealed siphonic drainage system to take most of the load off the retained historic rainwater goods.

Paint and Rust Removal

For localised repair and restoration of historic rainwater goods, in many cases old paint layers would need to be first removed. This can be done using environmentally friendly chemical paint strippers, low-abrasion methods such as wire brushing with copper wires, sandpaper, or dry blasting. Dry blasting is preferred as wet blasting may cause surface rusting of the cast iron. The iron should be cleaned to white metal level.

However, checks should also be made for the presence of lead in the historic paint layers, in which case, specialists support should be sought for lead abatement.

Crack repair by welding for cast iron downpipe.

Patching and Recoating

Shallow holes can be patched up with epoxy or putty to prevent water retention behind the paint. This can then be followed by treatment with anti-rust primer like zinc-rich primer, red oxide primer or micaceous iron oxide epoxy primer, followed by application of finishing coats. The compatibility of the new paint will need to be verified. Attention should be paid to hidden corners, poorly accessible areas, recessed areas etc., where water may collect.

For such metal heritage elements exposed to the weather, subsequent protective layer should be applied, and reapplied regularly in the long term maintenance regime.

Replacement and Welding

For partial replacement of badly damaged or corroded parts, new parts or new casting can be welded to the existing. The replacement parts should be of the same metal composition as the surrounding original parts to ensure compatibility and avoid bi-metallic corrosion. Welding can also be used for crack repair. Cast iron is difficult, but not impossible to weld – the work should be carried out by professional and experience welder. There are many methods of welding cast iron such as the traditional arc welding, metal inert gas welding and tungsten inert gas welding. There is a need to control the speed of welding and the current applied to prevent overheating and cracking of the cast iron. The use of nickel-based electrodes is recommended.

Maintenance

A common maintenance malpractice is to conceal defects such as rust, stains, minor cracks and peeling paint with a new coat of paint without properly addressing the underlying cause of these first signs of corrosion and breakage. This has often resulted in multiple layers of paint, some incompatible, that obscure the real condition and aggravate the deterioration.

Metal Roof Ornaments

Corrosion, paint peeling and staining observed around the anchor point and joints of a metal flag post mounted atop a copper dome roof.

Brass crucifix at Cathedral of the Good Shepherd. Crucifixes on top of church spires are often highly inaccessible, and usually repaired and restored when the main building undergoes major works.

Metal roof decorations include ridge ornaments, finials, flag posts, crucifixes on church roofs and antefixes or termination ornaments of roof coverings.

DETERIORATION & DIAGNOSTICS

Similar to rainwater goods, corrosion, cracking and breakages to cast iron roof ridge ornaments can also occur, though to a lesser degree due to lesser anchor points and reduced restraint in their installation. Unlike rainwater goods, these ornaments usually do not have chokage and water retention issues. Corrosion can nevertheless take place around the anchors where the ornaments are fixed to the roof.

CONSERVATION, INTERVENTION AND MAINTENANCE

Most exposed metal building components will have some form of anti-corrosion coating. Common forms of coating are paint and galvanising. Regular inspection should be carried out to ensure that there is no corrosion. Should corrosion be observed, prompt action to de-rust and repaint will ensure the longevity of the ornament.

Paint can be removed by environmentally friendly chemical stripper, or by wire brushing with copper wires or dry blasting. However, care should be taken not to damage or erode the features especially of fine filigree works such as cast iron roof ridge ornaments. Softer blasting or low-abrasion methods should always be attempted first.

In-situ repairs are best suited for ironworks not suffering from severe deterioration. Off-site repairs are to be made when there are severe corrosion and damages. The method of installation should also be determined to allow proper re-installation upon completion of the off-site repairs.

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Should there be any loss, and replacement with new casting is required, the new should match the original in size and appearance. The replacement parts should be of the same metal composition with the retained original parts. This is to ensure compatibility and avoid bi-metallic corrosion action.

For ornamental roof ridge, an accurate documentation of the features and missing parts should be made via drawings, photography or 3D scanning. Such recording should help to identify damaged or missing parts that need replacement or repairs.

Such roof ornaments, along with the pavilion they adorn, were usually ordered as a set off the same cast iron foundry catalogue and imported from UK in the colonial period. While the antefix is original, the ridge ornament behind has since been inappropriately replaced with a wrought iron replica.

Qianci (嵌瓷): Chinese Ceramic Shardwork

Shards cut from purpose-made glazed ceramic coloured bowls, secured in place with mortar, are used to create a variety of motifs.

Restored qianci figurine at Wak Hai Cheng Bio. The ceramic shards are used for clothes or draperies while the faces and limbs are usually moulded in plaster and painted with pigments.

In Singapore and around the region, it is not uncommon to find 3-dimensional and bas-relief ornamentation that is composed of cut ceramic shards secured with mortar, more commonly as decorations on roof eaves and ridges, but also seen on façades and interior walls, typically on buildings of Chinese origin or influence.

Ceramic shardwork, or *qianci* (嵌瓷) as termed in the Chaozhou region, is also known in the Minnan region as *jianci-diao* or *jianci* (剪瓷雕 or 剪瓷), while the term *jiannian* (剪黏) is widely used in Taiwan. It is widely acknowledged by scholars that the craft likely originated from the Chaozhou and neighbouring Zhangzhou region.

Shards used in qianci are mainly obtained from ceramic bowls that have been purpose-made in varied colours for the craft. The bowls are glazed on the external surface but left unglazed (bisque) on the inside. The exposed glazed surface takes well to weathering, while the porous 'back' allows for good adhesion to the mortar. More recent ceramic shardwork may incorporate other materials such as glass, mirror or metal parts. The mortar mix varies between different artisans and guilds, and is typically made from oyster shell lime with the addition of fibre for tensile strength, and may have sugar added as a plasticiser.

For qianci found on bas-relief on roof ridges or facades, mortar is applied on the plaster base (as part of the wall ornamental plaster), before the application of ceramic shards cut and shaped from bowls, to form a variety of motifs, from florae to faunae and human figures.

DETERIORATION AND DIAGNOSTICS

Qianci created with non-traditional coloured glass shards instead of ceramic – the pieces are thinner and finer, allowing for more detailed work, but also less durable and susceptible to chipping. Other defects here include dislodged and missing shards, pollution staining, and cracks on plaster base body.

Rainwater ingress into bedding mortar cracks leading to biological growth. Coupled with past lesser-skilled repairs and painting, the ensemble has lost its aesthetic and visual narrative coherence.

Visual Survey

The durability of qianci is dependent on its constituents, which in this case comprises the ceramics - specifically the glaze, the bedding mortar and plaster finish. Qianci on roofs and also facades is constantly exposed to environmental elements and generally deteriorate much faster than those under shelter. Appropriate and timely maintenance is also a key factor. Visible defects on the ceramic shardwork should be recorded during regular maintenance inspections and also mapped and documented prior to restoration works. This establishes the severity and distribution of the problem and will help in identifying possible causes of the damage:

- Natural photo-degradation occurs under long-term exposure to ultra-violet rays which causes the fading of painted plaster parts, especially the faces of human figurines, and the ceramic glazed layer
- Cracks in the bedding mortar and shards due to thermal expansion and shrinkage
- Rainwater ingress into the bedding cracks, leading to leaching and weakening of the mortar
- Dislodged and loosened ceramic shards due to weakened mortar
- Crazing, spalling or chipping of the tile glaze layer, arising from mismatched moisture content and rate of thermal expansion between the glaze layer and ceramic/lime body. This is particularly pronounced in ceramic elements with thick glaze layer and long term exposure to the elements. Whilst the 'cracks' are usually very fine and harmless, spalling and chipping of the glaze layer leave the clay body exposed and vulnerable
- Biological infestation due to water retention, and that causes more mortar cracks
- Efflorescence due to excess alkaline salts in Portland cement that was introduced in past inappropriate repairs
- Staining as a result of deposition of bird dropping and environmental soot

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Tactile Survey and Non-Destructive Tests

- Mechanical tapping on the tile surface for any hollow sound may be carried out to detect the presence of any cavity behind adhered ceramic tiles, which is a sign of debonding and possibly trapped moisture.
- However, the sound detection may be challenging given the small surface and thin tiles. In which case, cavity detection could be carried out by infrared thermography.

Sampling and Laboratory Analysis

If more in-depth diagnosis is required, such as for comprehensive restoration works, it may be occasionally necessary to extract samples of deteriorated tiles, mortar or plaster for further laboratory analysis. Material aspects to be studied include:

- Petrographic examination to analyse the integrity of the glaze layer, condition of the bedding mortar and its interaction with the tile body. This should be undertaken by an experienced petrographer or geologist familiar with ceramic tile and mortar bedding.
- Test for thermal and moisture expansion behaviour of the tiles
- Test for water absorption of the tiles
- Test for salt content and type found within the tiles

Glazed coloured ceramic bowls purpose-made for crafting qianci.

Current day bowls with synthetic colourants are usually brighter in hue than historic ceramic shardwork tinted with naturally occurring pigments, creating a challenge in patching work.

CONSERVATION, INTERVENTION,AND MAINTENANCE

Conservation Approach

The conservation strategies for ceramic shardwork ornamentation depends on several factors:

- Quality and appropriate use of constituent materials
- Location of ornaments – exposed or under shelter
- Scale of ornaments
- Extent of damage or degradation

The guiding conservation principle is to retain and restore as much original material as possible with minimal intervention or new works. If loss and defects are minimal, the ornaments are typically not restored.

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Appropriate Materials and Techniques

Where restoration, repair or new works are necessary, materials such as tiles, mortar, paint and plaster matching or compatible with the historic should be used. The particular craft tradition, usually of specific provenance or artisanal lineage, should be adhered to for coherence in style and technique. If it is deemed necessary for the painted plaster to be restored or touched up, secco painting technique – where the pigment mix is applied to dry plaster – should be used.

In some cases, non-traditional materials found in more recent ceramic shardwork may not have weathered or adhered well. These could then be replaced with another more durable, compatible and aesthetically similar material.

Restoration Repair

All loose or damaged underlying mortar will need to be removed by hand, followed by the reapplication of an appropriate mortar to adhere the original ceramic shards. In many cases, previous inappropriate repairs were undertaken using Portland cement - this should be completely removed.

A temporary roof is erected while skilled artisans are flown-in to undertake the delicate and painstaking work of restoring rooftop qianci at Wak Hai Cheng Bio.

If the removal of incompatible material would affect the integrity of the ornament, and if past repairs were substantial and executed in poor workmanship, it may be more prudent to replicate the ornament with traditional materials and techniques, than to attempt restoration.

Minor ornaments previously repaired with Portland cement, that neither affects the reading nor cause further deterioration to the rest of the ensemble, may also be left in place if the ornament is intact and in stable condition.

Maintenance

- Regular visual inspection should be carried out to look out for any signs of common deterioration.
- Special attention should be paid to the adhesion of ceramic shards to the underlying mortar, as well as that of the bas relief panels to the wall substrate.
- Given the vulnerability of these ornaments, any overhanging tree branches should be trimmed to prevent damage from impact.
- If dislodged or loose components are observed to be at risk of falling, the area should be cordon off or protective netting should be installed, while specialist advice is sought.

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Ceramic Stoneware

Stoneware roof ornaments found in Singapore, largely of Chinese origins, include green bottle balustrade at the roof parapet, as well as ridge ornamental vent tiles in *shiwan* (石湾) or *liuli* (琉璃) glazed ceramics, or unglazed terracotta. When glaze is fired onto a clay object, it seals the piece, making it stain resistant and therefore more robust when used as roof ornaments. These units are installed using mortar.

Refer to section on Ceramic Shardwork for elaboration on causes of common deterioration

DETERIORATION & DIAGNOSTICS

Similar to ceramic shardwork, common deterioration are, mostly due to long term exposure to the elements, or inappropriate maintenance, and generally can be identified through visual inspection:

- Natural photo-degradation.
- Deteriorated bedding mortar
- Moisture retention
- Dislodged or missing units
- Biological infestation
- Efflorescence
- Crazing, spalling and chipping of glazed ceramic layer
- Staining

Left: Terracotta vent tiles as roof ridge ornamentation. Right: Fine crazing on green glazed bottle balustrade.

Relevant non-destructive test methods include infrared thermography to detect the trapped moisture behind the surface, water ingress and the presence of cracks, and surface penetrating radar scan to establish the structural stability by identifying installation method and location of hidden supports, especially for the larger bottle balustrade units. Controlled breakout may be needed to ascertain the actual installation details.

CONSERVATION, INTERVENTION, AND MAINTENANCE

Patching of fine cracks on green glazed bottle balustrade.

Where the defects are minor, such as fine crazing of the glazed layer or staining, the original stoneware units should be retained; simple cleaning and patching of any small cracks with compatible non-cementitious putty and painted with matching colour, should suffice.

Incompatible material such as Portland cement from past repairs should be completely removed and the affected bedding redone with compatible mortar. Badly deteriorated bedding mortar should also be redone – if this is extensive, the stoneware units could be carefully dismantled, cleaned and repaired off-site and reinstalled using new compatible mortar.

Replacement is required in the case of missing or badly damaged units, such as those with spalling of the glaze layer. Stoneware of matching material and design would have to be sourced, or replicated.

Carved Timber

***Left:** Gable end finial and profiled fascia board at the Rectory of Cathedral of the Good Shepherd. **Middle:** Decorative timber fretwork that doubles as drip detail to break up the rainwater runoff. **Right:** Dentil-like fascia design composed of simple timber strips in alternating lengths.*

Local examples of historic carved timber roof ornaments include decorative fascia boards and gable end finials. These are usually made of tropical hardwood. Most fascia boards are a long, straight timber board that run along the roof eaves, meant to cover and protect the ends of roof rafters from moisture.

Fascia boards adorned with bas-relief carvings could also be found on Teochew and Cantonese traditional architecture.

A local rendition of the ornamental fascia board has small timber strips lined up in a row. Typically each unit comes with decorative fretwork and a pointed profile that also functions as a rainwater drip detail. This characteristic feature is often found on Malay houses, Anglo-Malay bungalows, and Straits Chinese shophouses and townhouses.

DETERIORATION AND DIAGNOSTICS

Common types of carved timber deterioration often, encountered along the fascia board are fungi attack (wet rot) and degradation by ultra violet radiation. Wet rot usually occurs at spots where there is trapped moisture, typically along junctions, joints and interfaces between the carved timber element and the roof rafters. Due to its exposure to the solar radiation, weathering of the carved timber often results in checks, splits and discolouration where the paint has failed. Termite infestation in such exposed timber is uncommon.

Left: *Paint peeling and wet rot of fascia board and supporting rafter end.*
Right: *Deteriorated shophouse fascia and soffit.*

CONSERVATION, INTERVENTION AND MAINTENANCE

Carved timber ornaments will require regular maintenance to upkeep their surface protective finish, either by means of painting, oiling or even gold gilding in order to extend their lifespan.

Where partial or complete replacement is needed, similar design and species of wood as the original should be used. The installation details should follow that of the original. Inherent design flaws or environmental factors that had caused deterioration such as moisture retention should be addressed – for example, trees in close proximity should be trimmed. The timber should be allowed to dry out following wet weather. The timber should also be treated with preservative to prevent future fungi attack.

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