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To the memory of John Ashurst (1937–2008), an inspiration and friend to all the editors, whose encouragement and support was a great motivation for this new series of Practical Building Conservation.

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METALS

Series Editors: Bill Martin and Chris Wood

Volume Editors: Sophie Godfraind, Robyn Pender, and Bill Martin

NOTES ON VOLUME EDITORS & CONTRIBUTORS

Volume Editors:
Sophie Godfraind, Robyn Pender, Bill Martin

Sophie Godfraind is an Architectural Conservator in the Building Conservation and Research Team at English Heritage. She is a trained wall-painting conservator, as well as specialising in the conservation of metals.

Dr Robyn Pender is also with the Building Conservation and Research Team, as a Senior Architectural Conservator. She is a building physicist, with training in wall-painting conservation.

Bill Martin is an architectural conservator with over 30 years' experience, and the Conservation Director of English Heritage.

Principal Contributors:
Patrick Baty, David Farrell, Rupert Harris, Geoffrey Wallis

Patrick Baty is a historian specialising in the paints and colours used to decorate historic buildings. **Dr David Farrell** is a corrosion engineer specialising in metal conservation. **Rupert Harris** is a conservator specialising in all types of metalwork; he is an official advisor to the National Trust, as well as to many museums and local authorities. **Geoffrey Wallis** is a metal-conservation consultant specialising in historic metalwork and machinery.

All the principal contributors are advisors to English Heritage, and the volume editors would like to take this opportunity to thank them for their help and support with this book, as well as the information and images they have so generously provided.

Other Contributors:

Jeremy Ashbee, Peter Clement, Keith Falconer, Tracy Manning, David McOmish, Geraldine O'Farrell, Sarah Pinchin, Graham Pledger, Wil Roberts, Peter Rumley, David Scantlebury, Jane Spooner, and Amanda White.

THE PRACTICAL BUILDING CONSERVATION SERIES

This series of *Practical Building Conservation* technical handbooks supersedes the original five volumes written by John and Nicola Ashurst, and published in 1988.

The series is aimed primarily at those who look after historic buildings, or who work on them. The ten volumes should be useful to architects, surveyors, engineers, conservators, contractors and conservation officers, but also of interest to owners, curators, students and researchers.

The contents reflect the work of the Building Conservation and Research Team, their colleagues at English Heritage, and their consultants and researchers, who together have many decades of accumulated experience in dealing with deteriorating building materials and systems of all types. The aim has been to provide practical advice by advocating a common approach of firstly understanding the material or building element and why it is deteriorating, and then dealing with the causes. The books do not include detailed specifications for remedial work, neither do they include a comprehensive coverage of each subject. They concentrate on those aspects which are significant in conservation terms, and reflect the requests for information received by English Heritage.

Building conservation draws on evidence and lessons from the past to help understand the building, its deterioration and potential remedies; this encourages a cautious approach. New techniques, materials and treatments often seem promising, but can prove disappointing and sometimes disastrous. It takes many years before there is sufficient experience of their use to be able to promote them confidently. Nonetheless, understanding increases with experience and building conservation is a progressive discipline, to which these books aim to contribute.

The volumes also establish continual care and maintenance as an integral part of any conservation programme. Maintenance of all buildings, even of those that have deteriorated, must be a priority: it is a means of maximising preservation and minimising costs.

Most of the examples shown in the books are from England: however, English Heritage maintains good relations with conservation bodies around the world, and even where materials and techniques differ, the approach is usually consistent. We therefore hope the series will have a wider appeal.

Dr Simon Thurley
Chief Executive, English Heritage

ABOUT THIS BOOK

This volume covers both structural and ornamental architectural metalwork, and includes introductions to some specialist fields of architectural metal conservation, but moveable objects such as metal furniture have specifically been omitted. Neither are metal roof coverings or metal reinforcement of concrete discussed in any detail, because these are dealt with in the *Roofing* and *Concrete* volumes of the *Practical Building Conservation* series.

The development of protocols for dealing with architectural metalwork has lagged behind that of other areas of building conservation. Until recently in England it was more common to replace metalwork than it was to treat or even to repair it, and such repairs as were made were more often entrusted to the local fabricator rather than to a specialist smith or conservator. It was rare to consider the possible long-term impacts of these interventions on the metalwork, let alone on the associated building materials. This is rapidly changing, but metalwork conservation remains a complex field. Revolutions in production technology since the Industrial Revolution have meant that some once-familiar materials have become rare, and this complicates both care and repair.

Architectural metalwork is enormously diverse, covering everything from decorative elements and supporting structural members to essential rainwater protection, and there have been almost as many different approaches to conservation as there have been different applications. It is certainly true that every situation is unique, but nevertheless there are some general principles that, thoughtfully applied, will allow the planning of treatment and long-term care. This book brings together the many current approaches to conservation, and formulates some general principles for wider use.

The book itself has four main sections. The first is a general introduction to architectural metalwork, which sets out the history of metal as an architectural material, and the conservation information common to all types of metal. The second section looks at the conservation of the iron-based ('ferrous') metals, such as wrought iron, cast iron and steel, which must be conserved in particular ways. With the one exception of stainless steel, ferrous metals do not develop a surface film which inhibits corrosion, and so will rust if not protected by paints and coatings. This section also includes an excursis on the conservation of corrugated iron. The third section considers the non-ferrous metals, with chapters on the conservation of lead, of copper-based metals such as copper, bronze and brass, of aluminium, and of zinc. These metals all naturally form protective surface films, so they deteriorate in different ways to iron and steel, and the ways they must be conserved are also different.

The final section of the book introduces a number of special topics in architectural metalwork conservation: metal-leaf decoration, statuary, and bells. These are usually the province of specialist conservators, and this section gives very brief introductions to the issues they must deal with, and the materials and methods that they use.

USING THESE BOOKS

For accessibility and ease of use, the information given in the text has not been footnoted, and rather than references, short lists of further reading are given at the end of the appropriate sections. References within the text are given in **bold**, and references to other publications in ***bold italics***.

Links to other books in the ***Practical Building Conservation*** series are indicated throughout the text by the relevant volume symbol, showing that more information on the topic will be found in that volume.

The other volumes in the series are:

- Conservation Basics BASICS
- Building Environment ENVIRONMENT
- Concrete CONCRETE
- Earth, Brick & Terracotta E B & T
- Glass & Glazing GLASS
- Mortars, Renders & Plasters MORTARS
- Roofing ROOFING
- Stone STONE
- Timber TIMBER

Although every attempt has been made to explain terms as they first occur in the text, a glossary has also been included, and can be found just before the index.

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INTRODUCTION

This chapter introduces the concerns common to the conservation of all types of architectural metalwork, including basic concepts of deterioration, methods of assessment, and planning treatment and repair.

Chemically, a metal is any element which easily loses electrons to form positive ions (cations). By this definition, metals are the dominant elements in nature, but the familiar metals are those that correspond to the *Oxford English Dictionary* definition: *"any of the class of elements including gold, silver, copper, iron, lead, and tin and mixtures of them (alloys, such as brass and bronze), characteristically lustrous, ductile, fusible, malleable solids that are good conductors of heat and electricity."* It is these metals which are used in architecture, and are dealt with in this volume of *Practical Building Conservation*.

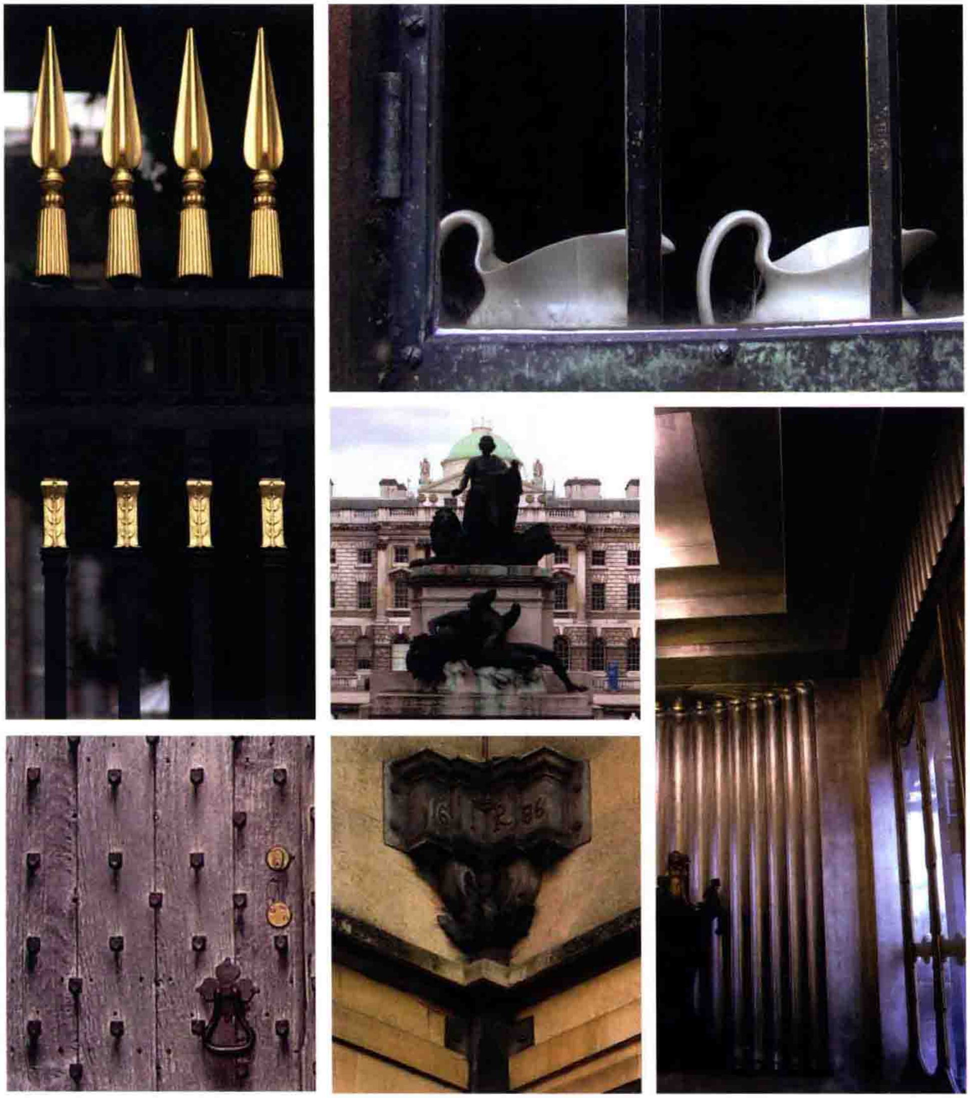
Metalworking is one of the oldest of the arts, although until the 13th century only seven metals were known and used pure or in alloys: gold, copper, silver, lead, tin, iron and mercury. The other metals used in architecture were not discovered until centuries later: cobalt, nickel and chromium in the 1700s, and aluminium in 1827. Zinc was known in China by 1400, but it did not come into common use in the West until the middle of the 18th century.

Every metal or alloy has its own unique characteristics and mechanical properties, which derive not only from the elemental composition and structure of the metal, but from the methods used in refining and forming it. How different metals can be cast or forged is governed by their basic physical and chemical characteristics, including malleability, brittleness and hardness, and this in turn governs how they can be used in buildings.

The other critical factor when choosing metals for architecture is resistance to oxidation, or 'corrosion'. Only a few very special metals – gold, platinum and palladium – do not react with the atmosphere at all. All others readily form cations if they are exposed to water, and these react with oxygen in the air to form metallic oxides. Corrosion can be instantaneous (as it is with potassium, which burns away in seconds), or gradual (as it is with iron, which rusts), or very slow (as it is for metals such as copper, zinc, nickel and aluminium, where the oxide layer is largely impermeable, and so slows further oxidation).

Metals have been used architecturally in many ways, and in any one building many types of metalwork may be found.

Because metals are strong, but still can be softened and reformed into almost any shape and size, they can perform tasks impossible for other building materials. By using metals for fixings and for main members, structures can be produced that would otherwise be impossible. Nails and screws, plates and wires can hold together or reinforce other building materials such as stone and timber. Bars and cables can be embedded into mortars and concretes to give them tensile strength, and metal beams can be made to span distances impossible for timber and other traditional building materials.



Metal is used in many ways in architecture

Clockwise from top left: Gilded railings at Clare College, Cambridge; bronze window frame, Tyntesfield; foyer of the Savoy Theatre, London; lead hopper and downpipe, Audley End, Suffolk; studded door at Powis Castle; courtyard of Somerset House, London, with copper dome and bronze statues.

Different metals have different characteristics: some, like iron, are hard and tough; others, like lead, are soft and malleable. Two or more metals can be combined together to form alloys like bronze and stainless steel that have their own particular characteristics. They can be shaped in different ways to form sheets, tubes, or complex components, and can be reused by melting and reforming.

Some metals and alloys are very resistant to wear and even to water, and those which are moisture-sensitive can often be successfully protected from corrosion by paints or other coatings, including coatings made from more corrosion-resistant metals.

In the past, the chief problem with metals as building materials was their cost: extracting, refining and shaping all demand vast quantities of energy, and energy was expensive. Even so, from the earliest days metals were used for many important building components, including roof sheets, rainwater disposal, nails and braces, hinges, gates and window frames, as well as for general repairs. When energy from fossil fuels became widely available during the Industrial Revolution, metal quickly became a dominant building material, and modernist architecture depends on metal framing, cladding and reinforcement.

Coloured woodcut from Gregor Reisch's *Margarita Philosophica*, 1535, showing metal mining.

4000 BC

6000 BC	5000 BC	4000 BC	3600 BC
Gold discovered.	Artefacts are being produced from pure natural copper.	Silver discovered. In Egypt and Sumer, small items such as the tips of spears are being fashioned from iron recovered from meteorites.	Artefacts being made from smelted copper in the Nile Valley. The oldest known casting, a copper frog from Mesopotamia, dates from 3200 BC.

HISTORY OF METALWORKING

Metals have been used from the earliest times. It is not possible to know which was the first metal to be extracted and worked, or when and where this took place, but it seems likely that it would have been in Mesopotamia, using some metal which could be found in pure form and could be worked using simple tools of timber, bone or stone (gold and copper are the two obvious candidates).

EXTRACTING METALS

Pure metals are rare in nature. Most are found in complex ores (rocks containing metal-bearing compounds, usually oxides), so to obtain enough metal for everyday use, it was necessary to develop technologies to mine ores and extract their metallic component.

MINING

In the earliest days of metalworking, ores were either collected from outcrops, or dug from open workings such as shallow quarries, drift mines or 'bell-pits'. True mines required new technologies to deal with the water that invariably floods deep shafts. The Romans used adits (horizontal side-shafts) to not only drain the workings, but to ventilate them, and water was sometimes extracted using pumps with shafts turned by animals or water mills. The invention of steam-driven pumps and ventilators in the 18th century enabled mines to be dug deeper than ever.

The most important mines were always those which yielded the most concentrated ores, particularly if they also happened to contain other minerals useful during refining. For example, in Coalbrookdale, iron ore was found alongside clay, limestone and coal, so it was there that Abraham Darby established his ironworking business in 1708.

3500 BC	2500 BC	2000 BC	1800 BC	1500 BC
Lead discovered.	Silver being manufactured by cupellation.	Iron first smelted. Evidence that ornamental weapons from Anatolia were made from smelted iron.	Tin smelting becomes common in Western Asia. Earliest tin artefacts.	In West Africa, iron is being smelted, and the Hittites develop crude iron metallurgy.

REFINING

To extract usable metal from ore, the unwanted material in the rock must first be removed, most often by crushing, sifting and washing, though chemical reduction is also used for certain metals. The metal oxides that are left must then be chemically reduced to form the metal itself, usually by 'smelting'. Copper, tin and lead mining seem all to have begun in the Middle East, and by 5000 BC copper was being extracted by smelting.

SMELTING

The ore is placed in contact with fuels such as charcoal or coke and heated to high temperatures; as the fuel burns it produces carbon monoxide gas, which scavenges the oxygen molecules in the metal oxides, forming carbon dioxide gas and leaving behind the metal atoms. Sometimes a flux such as lime is added to the mix. This combines with any impurities to form a liquid slag, which can be separately run out of the furnace.

By 2700 BC, bronze (an alloy of copper and tin) was being produced wherever the raw materials and fuel were to be found, and iron smelting – which requires much higher temperatures – had also begun in earnest.

OTHER FORMS OF EXTRACTION

Smelting has historically been used for iron, copper and lead, but not for zinc, which vaporises at high temperature. By contrast, very reactive metals such as aluminium are extracted via reduction through electrolysis. An electric current is passed between a positive and a negative electrode (the cathode and anode) through a bath containing metallic electrolytes or molten metal; pure aluminium is deposited onto the cathode, from which it can be recovered.

The chapters covering individual metals give details of each specific extraction process.

1400 BC

1400 BC	1200 BC	1000–800 BC	645 BC
Bronze is the predominant metal alloy. Evidence of brass objects from this period.	In India and Anatolia, smelting of iron in bloomeries begins, producing wrought iron. Ironmaking becomes an everyday process.	By 800 BC the Iron Age has reached central Europe. Earliest production of iron objects in British Isles (between 1100 BC and 900 BC).	Earliest known sand casting (in China).