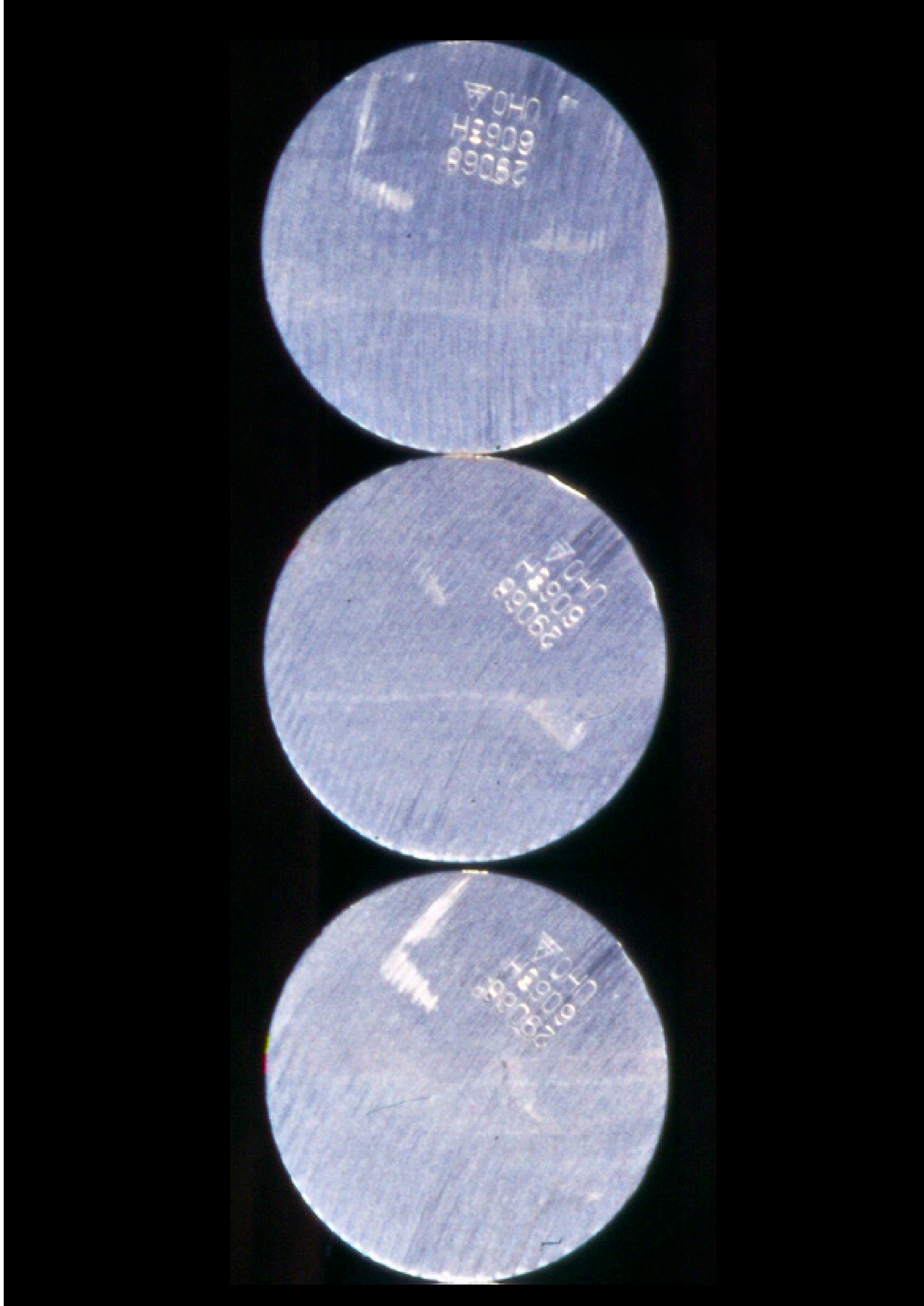
Aluminium and Durability

Towards Sustainable Cities

Michael Stacey



International Aluminium Institute

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Nottingham + Llundain

Front cover image credit: 1 Finsbury Avenue, London, architect Arup Associates, 1985, photographed by Michael Stacey.

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Aluminium and Durability
Towards Sustainable Cities

Michael Stacey Architects

ARCHITECTURE + TECTONICS RESEARCH GROUP

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Contents

Preface

This book is structured in nine primary chapters starting with an introduction, followed by an overview of aluminium that includes an exploration of how it can be finished. The earliest uses of aluminium in architecture and the built environment have been researched and are set out in Chapter Three, *Aluminium Pioneers.* This field of 50 projects, most of which are still in use, range in completion date from 1895 to 1986. This charts almost 100 years of the use of aluminium in architecture. From this list, four great works of architecture, based on a significant early use of aluminium, were selected for further study and in-depth site visits, as set out in Chapter Four, *Four Historic Exemplars: Architecture and Aluminium*.

The next chapter progresses to a more contemporary history of the use of aluminium in architecture. Twelve case studies were identified, researched and subjected to a detailed site study. The projects were selected on the basis that all are award-winning or historically important works of architecture incorporating a significant use of aluminium. These projects are predominantly located in the UK, with one in the USA; the dates range from 1940 to 1990. These projects were visited between the spring of 2012 and the summer of 2013. There is an intended overlap with the projects featured in Chapter Three. The two projects featured in both sections are the New Bodleian Library, Oxford (1940) and the former Alcoa Building, Pittsburgh (1953). To examine the durability of aluminium used to make architecture, the youngest project is over 20 years old.

From this set of 12 case study projects, four were identified for non-destructive testing by an independent testing house, Exova. This testing has been carried out on three projects: the New Bodleian Library, Oxford: Herman Miller Distribution Centre, Chippenham: and 1 Finsbury Avenue, London. This non-destructive testing is explained and illustrated in Chapter Six and the Exova report has been provided in full, see Appendix A.

Chapter Seven examines the role of maintenance in durability, providing comparative data on timber, PVCu, steel and aluminium, with an emphasis on window assemblies and the necessary maintenance cycles. This is followed by a chapter setting out the development of guarantees of finishes of aluminium on a global yet regional basis. The book closes with an interim conclusion including the recommendation that the service life of aluminium components should be extended, with recommended life expectancies of aluminium building components.

ONE

introduction

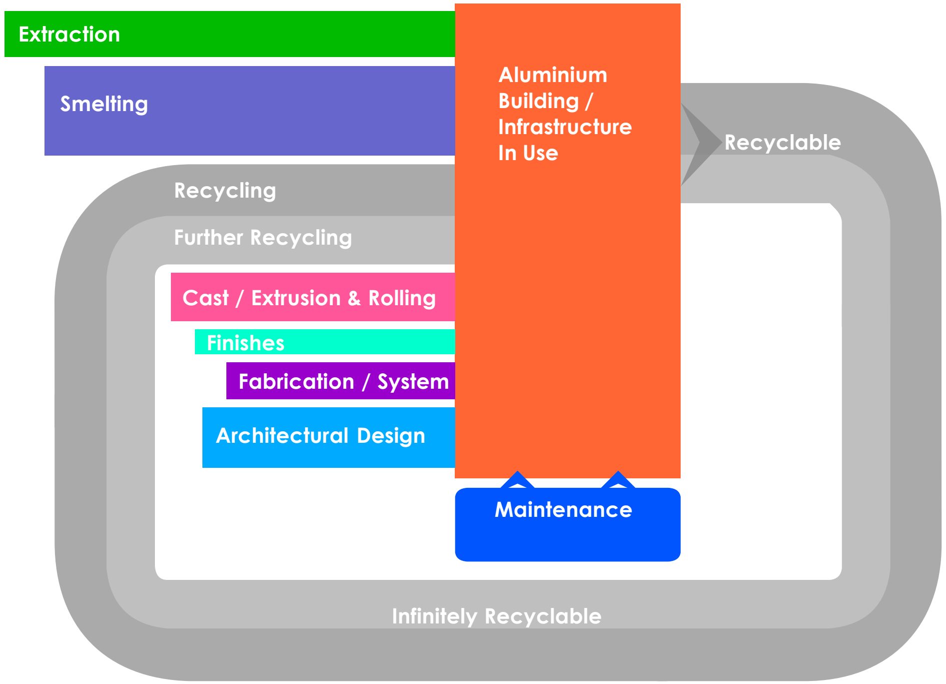


Fig 1.1 All participants add value to aluminium

Aluminium and Durability is the first report resulting from the Towards Sustainable Cities Research Programme. The objective of this research programme, funded by the International Aluminium Institute [IAI], is to quantify the in-use benefits of aluminium in architecture and the built environment. The programme was initiated by Chris Bayliss, Deputy Secretary General of IAI, and Michael Stacey of Michael Stacey Architects in the spring of 2012. Research collaborators include the Architecture and Tectonics Research Group [ATRG] of The University of Nottingham, and KieranTimberlake of Philadelphia, Pennsylvania, USA.

Michael Stacey is the research programme director and editor of this book, *Aluminium and Durability*. It was prepared with researchers Toby Blackman, Laura Gaskell, Jenny Grewcock, Michael Ramwell and Benjamin Stanforth, with input from Stephanie Carlisle and Billie Faircloth of KieranTimberlake.

The Towards Sustainable Cities Research Programme is structured around the primary benefits of aluminium, as articulated by the *The Future Builds with Aluminium* website (*http://greenbuilding.world-aluminium.org*), which is a sector-specific component of *The Aluminium Story* (*http://thealuminiumstory.com*). Towards Sustainable Cities is a three-year programme quantifying the in-use benefits of aluminium in architecture and the built environment.

A primary aim of this research is to quantify the in-use carbon benefits arising from the specification of aluminium in architecture and the built environment, to complement the relatively well-understood emission savings from the use of aluminium in transportation applications and through the recycling of aluminium scrap. A vital goal of this research is to quantify the potential contribution of aluminium towards the creation of sustainable cities – a key task now that over half of humanity lives in urban areas.

This first report focuses on durability, as this is probably one of the most important qualities that aluminium and aluminium alloys bring to the creation of high-quality contemporary architecture. Aluminium is long-lasting, yet is fully recyclable should the building become spatially or technologically redundant, for example due to a lack of space for up-to-date services.

The barriers to the use of aluminium and the many other benefits of aluminium to humankind when used to create architecture and infrastructure will be explored in later reports.

TWO

aluminium and finishing

Aluminium and Finishing

This chapter serves as an introduction to the material itself: aluminium. It also sets out the primary methods of finishing aluminium for architecture focusing on anodising, polyester powder coating and PVDF coating.

Aluminium

Aluminium is a silvery, soft, ductile, light metal. The chemical symbol for aluminium is Al, and it has an atomic number of 13. Alloyed with other metals such as copper, it has become the first-choice material for many contemporary uses. Aluminium is the third most abundant material in the Earth's crust and the most abundant metal. Aluminium is 8 per cent of the Earth by mass, typically found in the form of bauxite.

Aluminium can be cast, extruded, press-moulded and roll-formed, among other processes. Many of the forming processes exploit the inherent ductility of aluminium. It can be readily cast and recycled as its melting point is only just above 660°C. The recyclability of aluminium benefits from the retention of all of its material qualities after recycling, combined with the monetary and societal value of this metal.

> The reason aluminium smelting requires a lot of energy is the strong bond between aluminium and oxygen in alumina molecules (Al_2O_3). However, this reactivity is the chemical property that also gives the metal many of its valuable physical qualities, which makes it the material of choice in many applications.[1]

Aluminium has seven primary qualities that make it ideal for use in applications within architecture and the built environment:

1. durable;
2. recyclable;
3. flexible;
4. light and strong;
5. efficient or powerful;
6. economical;
7. sympathetic.

These qualities are explored in detail on *The Future Builds with Aluminium* website (http://greenbuilding.world-aluminium.org).

Durability is a vital quality of almost all architecture and construction. To achieve the direct socioeconomic benefits of the provision of workplaces and homes, durability is essential. It is

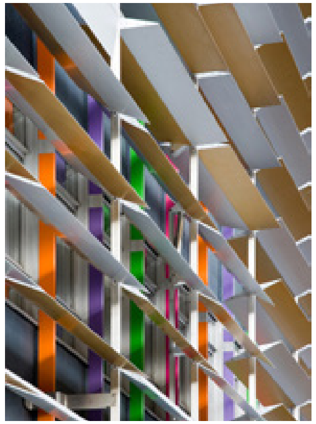


Fig 2.1 Colourful anodised louvres of Rich Mix, designed by Penoyre & Prasad Architects

also key to the provision of comfort and cultural continuity within architecture. Therefore, this research team considers it appropriate to begin with durability to start to quantify the in-use benefits of aluminium in architecture and the built environment.

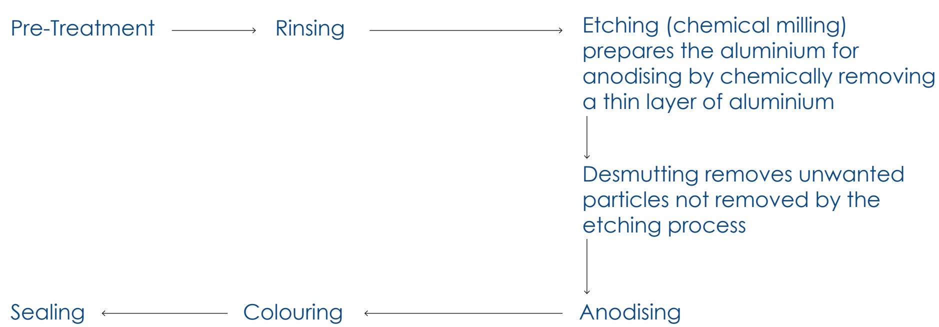
Aluminium and Finishing

Mill-finish aluminium will rapidly develop a coating of aluminium oxide on exposure to air. This forms a protective grey oxide coating on exposed aluminium components.

Anodising

Anodising, or anodic oxidation, is an electrolytic process that deposits a chemically stable oxide layer on the surface of the aluminium. The resultant oxide film is thicker and stronger than aluminium's natural oxide covering. It is hard, porous and transparent, and is an integral part of the metal surface so it will not peel or flake off. Once deposited, the oxide film can then be coloured, electrolytically or with organic dyes, before it is sealed. All anodised surfaces have a satin matt appearance arising from the base aluminium, unless chemical brightening or mechanical pre-treatment has taken place. Anodising is suitable for extruded, cast, rolled, drawn and forged aluminium products.[2] Anodising for external application requires a film thickness of 25 microns. As anodising is transparent, consideration of grain structure in sheet aluminium applications and dye quality and weld zones in extruded aluminium applications are visually important. Anodising was first used in architecture during the 1930s.

Fig 2.2 Anodising process



Silver or natural anodising is a clear, transparent anodised film, which shows the silver lustre of the underlying aluminium. It is achieved by omitting the colouring stage in the process sequence and going straight to sealing from anodising.

Electrocolour anodising results in a range of colours from light bronze to black. It is achieved by depositing cobalt or tin at the base of pores in the anodic film. The colour is produced by the absorption and reflection of specific light frequencies at an atomic level. For example, cobalt absorbs the blue element of the light falling on the surface, resulting in a bronze hue being reflected. As the colouration is obtained through optical effects dependent on atomic particle size, it is totally fade-free.

Interference anodising gives a spectrum of colours, of which blue-grey is the most practical. It is the result of light interference caused by nickel in the base of enlarged pores in the anodic film. Again, as the colour is the result of optical effects dependent on particle size, it is totally fade-free.[3]

Combination anodising provides a wide range of blues, reds, turquoises, greens and oranges, achieved by combining electrocolour bronze shades with lightfast organic dyes. Combination anodising is fade-resistant rather than totally fade-free.

Polyester Powder Coating

Powder coatings are solvent-free paints applied to metals and other conductive surfaces. The coating is applied electrostatically and is cured under heat to allow the flow and formation of a hard finish that is tougher than conventional paint. Powder coatings yield less waste compared to liquid coatings and do not require a solvent to keep the binder and filler in a liquid suspension form. Polyester powder coating is a two-stage process. First, a manufacturer produces the powder; second, the powder is applied to the surface of the aluminium components.

There are two types of powder coatings, thermosetting coatings and thermoplastics (reflecting the fundamental types of synthetic polyester plastics). Thermosetting coatings include a cross-linker in the formulation; when the powder is baked, it reacts with other chemical groups, increasing the molecular weight and improving performance properties. By contrast, thermoplastics do not undergo any additional reactions during the baking process; they simply melt to create the final powder coating.[4]

Today, powder can be produced without the use of organic solvents. This ensures there is no volatile release of organic compounds (VOCs) into the atmosphere. The method of application allows the powder coating to be applied in a single process. Excess powder is extracted, collected and reused, therefore the application process results in higher efficiency, lower wastage and is cost-effective.[5]

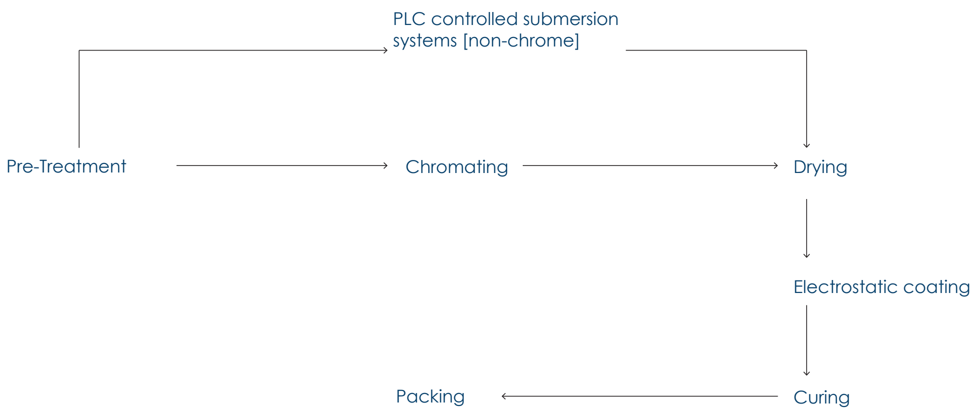


Fig 2.3 Powder coating process

Fig 2.4 Electrostatic application of polyester powder coating, courtesy of Nordson

Production:

- The polymer granules are mixed with hardener, pigments and other powder ingredients.
- The mixture is heated in an extruder.
- The extruded mixture is rolled flat, cooled and broken into small chips.
- The chips are milled to make a fine powder.

Application:

- part preparation or pre-treatment – the removal of oil, soil, lubrication greases, metal oxides and welding scales;
- powder application;
- curing.

Polyvinyl Fluoride Coating

Polyvinyl fluoride (PVDF or PVF_2) coatings are based on a mixture of polyvinylidene fluoride resin (minimum 70 per cent) and acrylic resin (maximum 30 per cent). This is not commercially available in powder form and therefore needs to be sprayed using wet techniques. PVDF coating is a multi-coat system requiring a colour coat and a top clear coat, so PVDF paints are relatively expensive. This method of finishing aluminium is less economical than powder coating. However, PVDF coatings have very high resistance to ultraviolet light and are therefore popular in regions of high insolation or sun-drenched regions such as the Middle East and the southern USA. PVDF coatings are not as scratch-resistant as polyester powder coatings, but offer greater resistance to weathering, staining, chalking and fading.[6]

Pre-treatment

Pre-treatment replaces the natural oxide film of aluminium and can be a chemical process or an electrolytic process. Correct surface preparation of the metal is vital to ensure that the powder coating gives the full durability as expected by the coating manufacturer. Pre-treatment of aluminium involves a multi-stage aqueous process applied by either spray, rollers or immersion, which includes cleaning, surface etching and conversion coating of the metal.[7]

Chromate conversion coating is a well-established pre-treatment method used before the application of polyester powder coating. However, a recent EU directive (2000/S3/EC) recognises the environmental hazards of using heavy metals and requires them to be phased out by September 2017.[8] Applicators are progressively renewing technology and removing chrome from the pre-treatment process. Alternatives include flash anodising or an automated titanium/zirconium base pre-treatment line.

Notes

1 *The Aluminium Story*, www.thealuminiumstory.com (accessed August, 2013).
2 Based on guidance from the Aluminium Finishing Association [AFA], www.afauk.org.uk (accessed August, 2013).
3 Ibid.
4 CurveX Temperature Profiling Systems, *Powder Coating*, available online at www.curvex.nl/applications/powder-coating (accessed August, 2013).
5 Interpon, *Sustainability*, available online at www.interpon.com/about-us/sustainability (accessed August, 2013).
6 Based on guidance from the AFA, www.afauk.org.uk (accessed August, 2013).
7 Based on guidance from the AFA on Architectural Powder Coating, www.afauk.org.uk (accessed August, 2013).
8 Chromate conversion coating pre-treatment is currently also used prior to the wet application of PVDF onto aluminium.

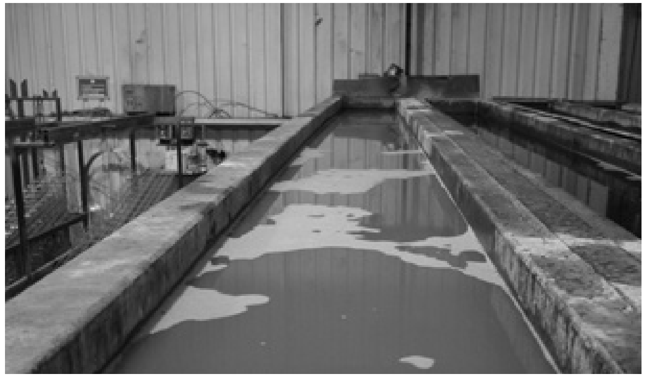


Fig 2.5 Pre-treatment is critical to the durability of polyester powder coating: Cleaning Tank 1 at Powdertech

Fig 2.6 Computer-controlled automated polyester powder coating line at Powdertech, which achieves very even coverage, combined with full recycling of unused powder

Fig 2.7 Interpon electrostatic thermosetting powders

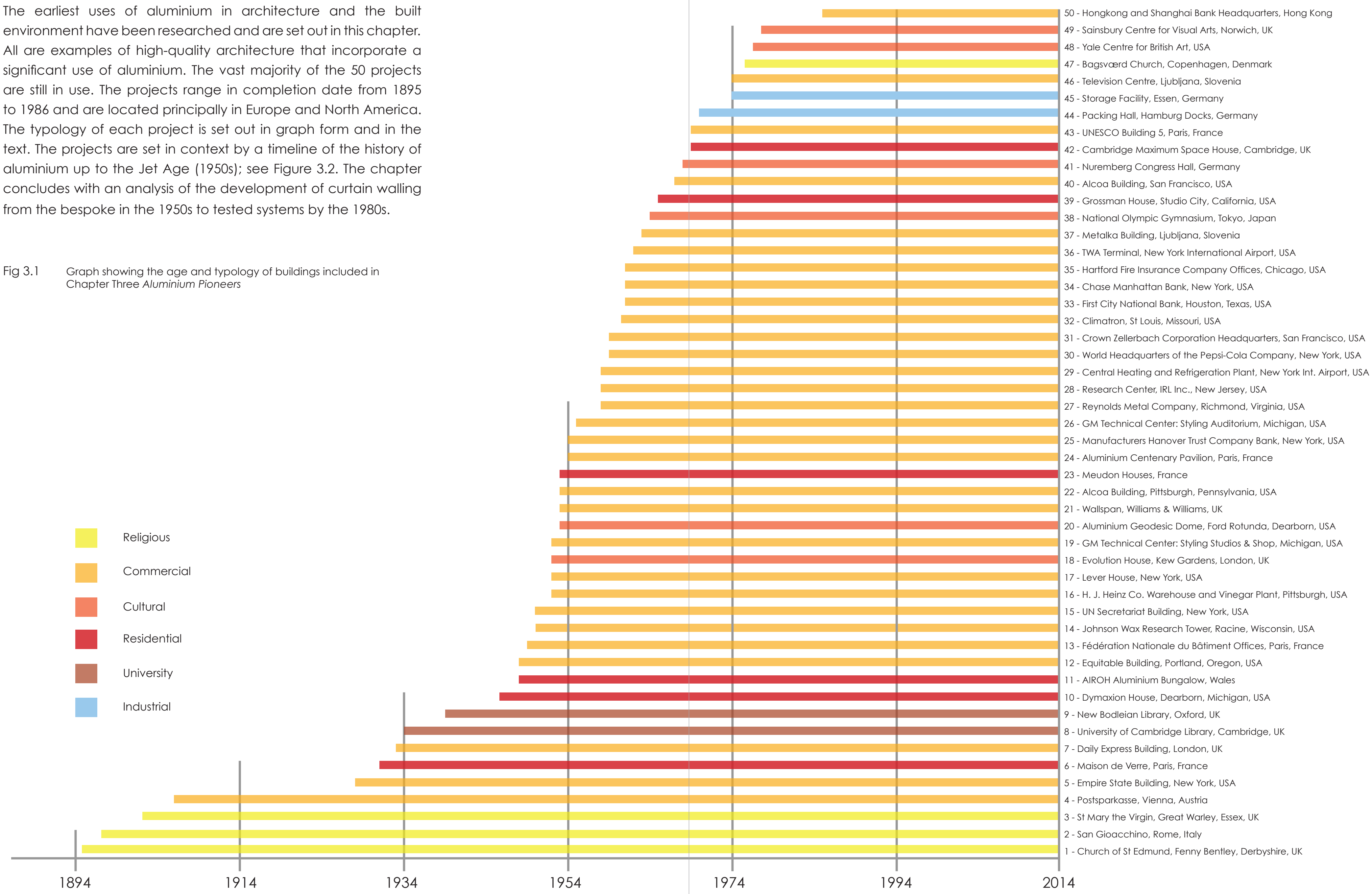
THREE

aluminium pioneers

Aluminium Pioneers

The earliest uses of aluminium in architecture and the built environment have been researched and are set out in this chapter. All are examples of high-quality architecture that incorporate a significant use of aluminium. The vast majority of the 50 projects are still in use. The projects range in completion date from 1895 to 1986 and are located principally in Europe and North America. The typology of each project is set out in graph form and in the text. The projects are set in context by a timeline of the history of aluminium up to the Jet Age (1950s); see Figure 3.2. The chapter concludes with an analysis of the development of curtain walling from the bespoke in the 1950s to tested systems by the 1980s.

Fig 3.1 Graph showing the age and typology of buildings included in Chapter Three *Aluminium Pioneers*



No.	Building / Location / Architect / Date[1]	Key Observation	Age (Years) [1]
1	**Church of St Edmund, King and Martyr, Fenny Bentley, Ashbourne, Derbyshire, UK: 1895**	Aluminium ceiling panels in the Beresford family chapel, painted by Alice M. Erskine in 1895, with the aluminium probably supplied by British Aluminium Works. This ceiling is in very good condition after 120 years.	**120**
2	**San Gioacchino, Rome, Italy: Architect Raffaele Ingami, 1897**	The cladding of the cupola of the church was a very early use of aluminium.	**118**
3	**St. Mary's Great Warley, Essex, UK: C. Harrison Townsend with Sir William Reynolds-Stevens, 1902**	Art Nouveau interior using aluminium.	**113**
4	**Postsparkasse, Vienna, Austria: Architect Otto Wagner, 1906**	First world class project to use aluminium.	**109**
5	**Empire State Building, New York, USA: Architect William F. Lamb, 1931**	Cast aluminium spandrel panels.	**84**
6	**Maison de Verre, Paris, France: Ensemblier Pierre Chareau, 1932**	Aluminium components on doors and exposed surfaces.	**83**
7	**Daily Express Building, Fleet Street, London, England: Architect Ellis & Clarke with Sir Owen Williams, 1932**	Bright aluminium proto-curtain walling cover strips, which secure vertically toughened glass	**83**
8	**University of Cambridge Library, Cambridge, England: Architect Sir Giles Gilbert Scott, 1934**	Anodised aluminium windows.	**81**
9	**New Bodleian Library, Oxford, England: Architect, Sir Giles Gilbert Scott, 1940**	Anodised aluminium windows.	**75**
10	**Dymaxion House, Dearborn, Michigan, USA: Engineer Richard Buckminster Fuller, 1946**	Aluminium sections with aluminium cladding and aluminium floor decking.	**69**
11	**Aluminium Bungalow, Museum of Welsh Life, St Fagan's, Wales: AIROH [Aircraft Industries Research Organisation on Housing], 1948**	Extruded aluminium floor, wall and roof sections with aluminium cladding and aluminium roof finish.	**67**
12	**Equitable Building, Portland, Oregon, USA: Architect Pietro Belluschi, 1948**	Proposed as composite aluminium cladding, executed as aluminium plate.	**65**
13	**Fédération Nationale du Bâtiment Offices, Paris, France: Architects Gravereaux & Lopez, Façade Design Jean Prouvé, 1949**	Unitised aluminium curtain walling, with a module of 1450, weighing only 92Kg.	**—**
14	**Johnson Wax Research Tower, Racine, Wisconsin, USA: Architect Frank Lloyd Wright, 1950**	Pioneering tubular glass and aluminium glazing system.	**65**
15	**UN Secretariat Building, New York, USA: Executive architect Harrison & Abramovitz, (1947—53)**	Arguably the first aluminium curtain-walling project in New York.	**63**
16	**H. J. Heinz Co. Warehouse and Vinegar Plant, Pittsburgh, Pennsylvania, USA: Architect Skidmore, Owings & Merrill, 1952**	36" curtain-walling module with aluminium mullions.	**63**
17	**Lever House, New York, USA: Architect Skidmore, Owings & Merrill, 1952**	The second curtain wall installed in New York, stainless steel-based curtain walling replaced with aluminium under the direction of Skidmore, Owings & Merrill in 2001.	**63**
18	**Evolution House, Kew Gardens, London, UK: Architect S. L. Rothwell, 1952**	Precedent for aluminium greenhouses.	**63**
19	**General Motors Technical Center Styling Studios & Shop, Warren, Michigan, USA: Architect Eero Saarinen, 1952**	5' module and the world's first gasketed curtain walling, on extruded aluminium mullions.	**63**
20	**Aluminium Geodesic Dome, Ford Rotunda, Dearborn, Michigan, USA: Engineer Richard Buckminster Fuller, 1953**	All aluminium geodesic structure on Albert Kahn's Rotunda from 1933, burnt down in 1962.	**9**
21	**Wallspan, UK: Williams & Williams, 1953**	Product described as the UK's first curtain-walling system by David Yeomans.[2]	**—**
22	**Alcoa Building, Pittsburgh, Pennsylvania, USA: Architect Harrison & Abramovitz, 1953**	The 30-storey Alcoa Building was clad in open-jointed aluminium unitised curtain walling.	**62**
23	**Meudon Houses, France: Architect Andre Sivé and Henri Prouvé with Engineer/Fabricator Jean Prouvé, 1953**	Sheet aluminium roof and aluminium mullions.	**62**
24	**Aluminium Centenary Pavilion, Paris, France: Architect Jean Prouvé, 1954**	Celebratory project by the great French pioneer of light metal tectonics.	**61**
25	**Manufacturers Hanover Trust Company Bank, New York, USA: Architect Skidmore, Owings & Merrill, 1954**	Fifth Avenue bank, very transparent and modern.	**61**
26	**General Motors Technical Center Styling Auditorium, Warren, Michigan, USA: Architect Eero Saarinen, 1955**	Aluminium shingles cladding on an aluminium dome.	**60**

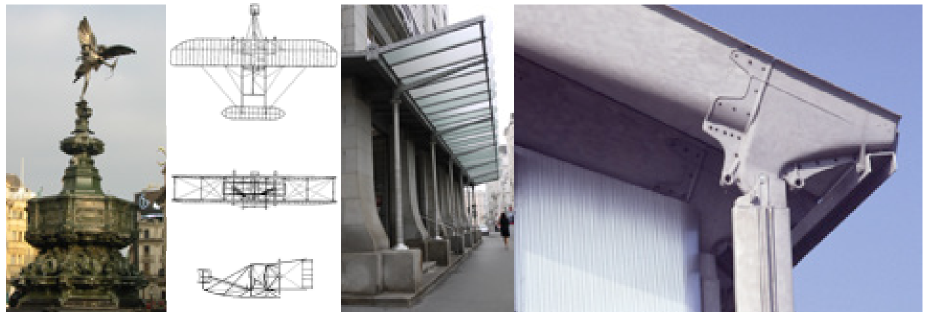
No.	Building / Location / Architect / Date[1]	Key Observation	Age (Years) [1]
27	**Reynolds Metal Company, Richmond, Virginia, USA: Architect Skidmore, Owings & Merrill, 1958**	Crisp modern office for an aluminium company that includes adjustable extruded aluminium external solar shading.	**57**
28	**Research Center, Industrial Reactor Laboratories Inc., Plainsboro, New Jersey, USA: Architect Skidmore, Owings & Merrill, 1958**	Aluminium cladding to an egg-like dome.	**57**
29	**Central Heating and Refrigeration Plant, New York International Airport, USA: Architect Skidmore, Ownings & Merrill, 1958**	Crisp industrial building clad with an I-beam aluminium curtain-walling system.	**57**
30	**World Headquarters of Pepsi-Cola Company, New York, USA: Architect Skidmore, Owings & Merrill, 1959**	A small, crisp office building in Manhattan, now listed by the Landmarks Preservation Commission.	**56**
31	**Crown Zellerbach Corporation Headquarters, San Francisco, California, USA: Architect Skidmore, Owings & Merrill, 1959**	Almost a system-based aluminium curtain-walling system.	**56**
32	**Climatron, St Louis, Missouri, USA: Engineer Richard Buckminster Fuller, 1960**	Tubular aluminium frame.	**55**
33	**First City National Bank, Houston, Texas, USA: Architect Skidmore, Owings & Merrill, 1961**	Visible neoprene gasketed aluminium curtain-walling system.	**54**
34	**Chase Manhattan Bank, New York, USA: Architect Skidmore, Owings & Merrill, 1961**	External I-beam aluminium curtain-walling system.	**54**
35	**Hartford Fire Insurance Company Offices, Chicago, USA: Architect Skidmore, Owings & Merrill, 1961**	Grey anodised aluminium cladding.	**54**
36	**TWA Terminal, New York International Airport, USA: Architect Eero Saarinen, 1962**	Gasketed curtain-walling system on an extruded aluminium carrier with steel trusses.	**53**
37	**Metalka Building, Ljubljana, Slovenia: Architect Edo Mihevc, Façade Design Branko Kraševac, 1963**	Aluminium curtain walling with pressed anodised aluminium panels, is silver with a little golden reflectivity.	**52**
38	**National Olympic Gymnasium, Tokyo, Japan: Architect Kenzo Tange, 1964**	Expanded aluminium acoustic celling and main external cables are wrapped in concrete and clad in aluminium jackets.	**51**

No.	Building / Location / Architect / Date[1]	Key Observation	Age (Years) [1]
39	**Grossman House, Studio City, California, USA: Architect Raphael Soriano, 1965**	Billed as 'The first all aluminum home.'	**50**
40	**Alcoa Building, San Francisco, USA: Architect Skidmore, Owings & Merrill, 1967**	A mature example and almost the end of SOM's experimental phase in its use of aluminium curtain walling. Not as famous as the John Hancock Tower by SOM in Chicago, 1970.	**48**
41	**Nuremberg Congress Hall, Nuremberg, Germany: Architect Ludwig & Franz Ruff, 1968**	Tested by the German Federal Institute for Materials Research and Testing [BAM] which commented that it is in a very good condition.	**47**
42	**Cambridge Maximum Space House, Cambridge, UK: Architect John Hix, 1969**	Used as a University of Cambridge School of Architecture Research Building and the early home of the Martin Centre.[3]	**15**
43	**UNESCO Building 5, Paris, France: Architect Bernard Zephus, Façade Design by Jean Prouvé, 1969**	Anodised aluminium cladding and extruded aluminium window frames with nylon thermal breaks.[2]	**—**
44	**Packing Hall, Schumacherwerder Overseas Centre, Hamburg, Germany: 1970**	Tested by BAM, which commented that the aluminium standing seam roof is in a very good condition.	**45**
45	**Storage Facility, Essen, Germany: 1974**	Tested by BAM, which commented that the aluminium standing seam roof is in a very good condition.	**41**
46	**Television Centre, Ljubljana, Slovenia: Architect France Rihtar, Façade Design Branko Kraševac, 1974**	Horizontally cast aluminium cladding.	**41**
47	**Bagsværd Church, Copenhagen, Denmark: Architect Jørn Utzon, 1976**	Velux Roof Lights.	**39**
48	**Yale Center for British Art, New Haven, Connecticut, USA: Architect Louis I. Kahn, 1977**	Aluminium louvres and aluminium roof light frames, a rare use of aluminium by Louis I. Kahn.	**38**
49	**Sainsbury Centre for Visual Arts, Norwich, England: Architect Foster Associates, 1978**	Interchangeable modular aluminium panel system.	**37**
50	**Hongkong and Shanghai Bank Headquarters, Hong Kong: Architect Foster Associates, 1986**	Aluminium curtain walling, brise soleil and rainscreen cladding	**29**

Notes

1 This is the age of the building in 2015, typically based on the date of completion of the project, therefore in the case of external aluminium windows, curtain walling, cladding or roofing the building fabric may well have been exposed to the elements longer than stated.
2 Verification of current status in progress, or entry is a product not a building.
3 Estimate that CMS House was operational for 15 years, prior to recycling.

Timeline of Aluminium up to the Jet Age



1800 – 1960

- **1808** Aluminium is discovered by Sir Humphry Davy as a constituent of alum, in England
- **1821** Pierre Berthier discovers bauxite ore in Les Baux-de-Provence, southern France
- **1825** H. C. Ørsted produces significant quantities of aluminium, in Denmark
- **1827** Friedrich Wöhler isolates aluminium, in Germany
- **1854** Henri Étienne Sainte-Claire Deville enhances Wöhler's method of isolating aluminium and chemical production of aluminium commences in France
- **1855** Aluminium spoons and forks used by visiting dignitaries at the Court of Napoléon III, in France
- **1858–60** Aluminium casting of Diane de Gabies by Paul Morin et Cie, in France
- **1884** Cast aluminium pyramid cap to the Washington Monument, in USA
- **1886** Hall-Héroult process – affordable volume production of aluminium invented by Charles Martin Hall and Paul Héroult
- **1887** Bauxite refining, the Bayer process is invented & patented by Austrian scientist Karl Josef Bayer
- **1888** Pittsburgh Reduction Company founded to develop the Hall-Héroult process
- **1890** First use of aluminium for overhead electric power cables
- **1891** First aluminium boat fabricated in Switzerland
- **1892** Cast aluminium sculpture of Eros at Piccadilly Circus, London
- **1895** Aluminium ceiling installed at Church of St Edmund, King & Martyr, Derbyshire, Fenny Bentley
- **1897** Aluminium sheet cladding of the cupola of the church of San Gioacchino, Rome
- **1902** Aluminium is the key material in the interior of St Mary the Virgin, Great Warley, Essex
- **1903** First powered flight by Wright brothers, Kill Devil Hills, USA, using a cast aluminium engine
- **1903** Alfred Wilm invents Duraluminium in Germany
- **1906** Otto Wagner's Postsparkasse, Vienna – cast and sheet aluminium
- **1920s** Development of anodising and aluminium extrusion processes
- **1931** Empire State Building, New York, USA, by William F. Lamb: cast aluminium spandrel panels
- **1934** Anodised aluminium windows installed at University of Cambridge Library, architect Sir Giles Gilbert Scott
- **1940** Anodised aluminium windows installed at New Bodleian Library, architect Sir Giles Gilbert Scott
- **1949** Unitised aluminium curtain walling by Jean Prouvé for Fédération du Batiment Office, Paris
- **1950s** Pioneering of aluminium curtain walling in USA
- **1950** UN Secretariat Building, New York, clad in aluminium curtain walling, executive architects Harrison & Abramovitz
- **1953** Alcoa Building 'The worlds first aluminium skyscraper', Pittsburgh, by Harrison & Abramovitz
- **1954** Jean Prouvé's Aluminium Centenary Pavilion is built to celebrate the 100th anniversary of the industrial production of aluminium in France
- **1957** Jean Prouvé designs extruded aluminium curtain walling for CIMT

Fig 3.2 Timeline of the history of aluminium up to the Jet Age

Church of St Edmund, King and Martyr, Fenny Bentley, Ashbourne, Derbyshire, England: 1895

One of the earliest recorded uses of aluminium within the realm of architectural construction is at the Church of St Edmund, King and Martyr, Fenny Bentley. The ceiling of the Beresford family chapel in the north-west corner of the church is made of decorated aluminium panels with additional wooden bosses, 'carved by members of the rector's wood-carving class, one of which shows the date of 1895', when the ceiling was installed.[1]

The painted aluminium panels present a remarkable set of components for this time period. In 1888, 'the price of aluminium produced in Stoke-on-Trent was £3,000 a ton, with a production rate of about 85 tons per year'.[2] The introduction of the electrolytic process in the decade after 1886 began to reduce production costs. It is therefore possible that the aluminium sheets were 'pre-production prototypes given to the church by A. S. Bolton of Oakamoor, a director of the British Aluminium Works of Milton in Stoke-on-Trent'.[3]

Fig 3.3 Church of St Edmund, King and Martyr, Fenny Bentley

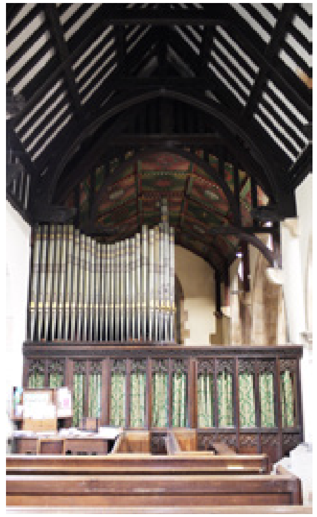


Fig 3.4 Beresford family chapel: aluminium ceiling panels fitted in 1895 and organ installed in 1879

The '30 panels of 99.1% purity aluminium' are thought to be '0.033' (0.84 mm) thick'.[4] The aluminium shows very little sign of ageing and there has been no record of maintenance since it was installed 120 years ago. The vibrant ceiling panels, painted by Alice M. Erskine in 1895, still display with clarity the detail with which they were originally painted.

Notes

1 Extract from Fenny Bentley church leaflet citing *company focus: hoogovens, Feb. 1998*, found during a visit to the church on 13 November 2013.
2 Canon D. Buckley (1987), *The Parish of Fenny Bentley and Its Church of St Edmund, King and Martyr, Ashbourne*.
3 Extract from Fenny Bentley church leaflet citing *company focus: hoogovens, Feb. 1998*, found during a visit to the church on 13 November 2013.
4 E. W. Skerrey (1982), *Long-Term Atmospheric Performance of Aluminum and Aluminum Alloys*, Wiley, New York, p. 330.

Fig 3.5 Aluminium ceiling panels, painted by Alice M. Erskine in 1895

San Gioacchino, Rome, Italy: Architect Raffaele Ingami, 1897

San Gioacchino in Prati Church was designed by the architect Raffaele Ingami (1836–1908). The dome of this church, completed in 1897, is the earliest extant example of external aluminium cladding. The 1.3mm thick aluminium cladding was selected for its lightness, durability and economy. The aluminium cladding of the dome has been inspected and tested during its more than 118 successful years of service. For further information, see Chapter Four.

Fig 3.6 San Gioacchino, Rome

St Mary the Virgin, Great Warley, Essex, England: Architect Charles Harrison Townsend with Sir William Reynolds-Stevens, 1902

St Mary the Virgin is a Grade I listed parish church designed by Charles Harrison Townsend in collaboration with the sculptor and interior designer Sir William Reynolds-Stevens. This is one of only three Art Nouveau church interiors in the UK. This church possesses an aluminium interior, celebrating the material for its value, durability and decorative character. The hemispherical dome of the church's apse is clad in aluminium leaf, which is embossed and adorned with cherry-red grapes. The nave is articulated by arches that carry embossed aluminium organic bas-reliefs, which are all signed by Sir William Reynolds-Stevens. Charles Harrison Townsend, who designed the Whitechapel Art Gallery (1899) and the Horniman Museum (1901) was one of England's leading Art Nouveau architects.

Although this interior is characteristically Art Nouveau, which is rare in England, it also demonstrates Arts & Crafts influences – particularly in the palette of other materials selected, including beaten copper for the pulpit with brass and even mother of pearl in the rood screen. A. L. Baldry's review of the church in *The Studio* magazine (1905) considered aluminium to be an appropriate and durable part of this material palette.[1] For further information, see Chapter Four.

Note

1 A. L. Baldry (1905), *A notable decorative achievement by W. Reynolds-Stephens*, The Studio, 34(143), pp. 3–15.

Fig 3.7 The intricate aluminium leaf and aluminium embossed details, a key component of the interior of St Mary the Virgin, Great Warley, Essex

Postsparkasse, Vienna, Austria: Architect Otto Wagner, 1906

The Austrian Postal Savings Bank or Postsparkasse, designed by Otto Wagner and completed in 1906, is clad in 100mm thick granite and 20mm thick Sterzing marble. This stone cladding is fixed to the structure with 17,000 steel bolts, protected from corrosion by lead with aluminium caps. The construction was completed in 16 months; this speed of construction was largely due to the bolted cladding system.

Postsparkasse is a great work of early modernism. Aluminium is used extensively in its construction, interior and furnishings. The steel columns of the translucent glass entrance canopy are clad in aluminium. Above on the cornice stand 4.5m-high cast aluminium sculptures of winged female figures. In the banking hall the steel structure is also clad in aluminium and the tubular aluminium heaters warmed the space. Even the Thonet chairs where made more durable by the use of aluminium feet.

For further information, see Chapter Four.

Fig 3.8 Postsparkasse, Vienna

Fig 3.9 [right] Postsparkasse: the main banking hall

Empire State Building, New York, USA: Architect William F. Lamb, 1931

The Empire State Building, designed by William F. Lamb, of Shreve, Lamb & Harmon, was completed in 1931 and has a steel frame clad in vertical bands of masonry with limestone alternating with steel-framed windows and cast aluminium spandrel panels. A wythe (a single leaf of masonry) forms the wall behind the cast aluminium spandrel panels, which were described as ornamental, yet have a role like a contemporary rainscreen panel. Prefabrication of components enabled the construction to be completed in one year and 45 days. In 1993, the Empire State Building was refurbished, during which all 6,400 corroded steel windows were replaced; the original aluminium spandrel panels did not require refurbishment.

James Ashby records other examples of the ornamental use of cast aluminium in architecture between the two World Wars. Many of them located in North America including the cast aluminium lamps of the US Custom House in Philadelphia in 1933, by sculptor Edward Ardolino.[1]

Note

1 J. Ashby (1999), *The Aluminium Legacy: the History of the Metal and its Role in Architecture*, Construction History Vol. 15, pp. 79–90.

Fig 3.10 Isometric drawing showing the detail of the assembly of the window and cast aluminium spandrel panel of the Empire State Building

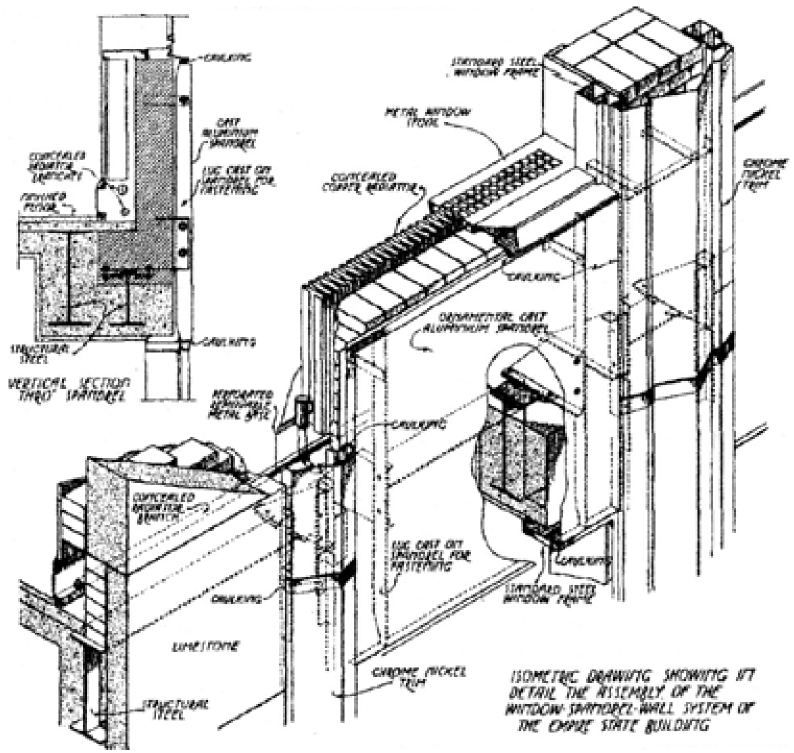


Fig 3.11 [right] Empire State Building

Maison de Verre, Paris, France: Ensemblier Pierre Chareau, 1932

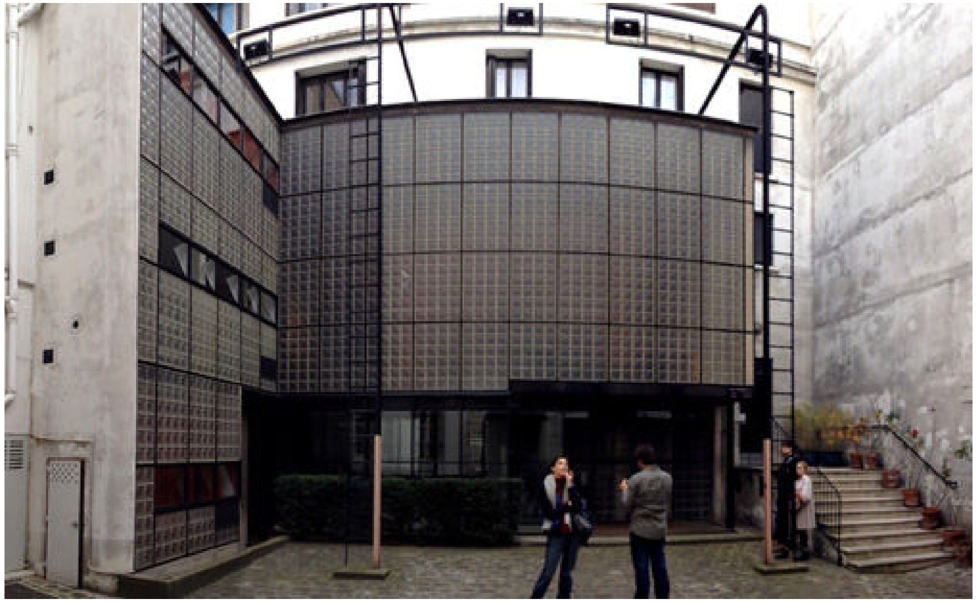
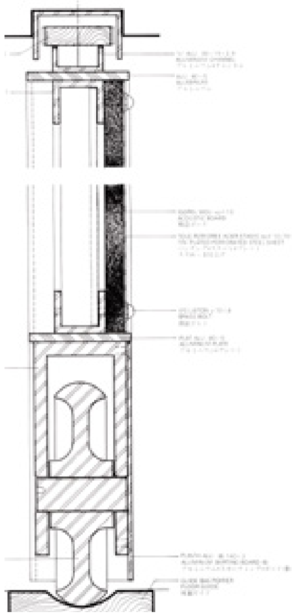


Fig 3.12 Front elevation of Maison de Verre, viewed from the courtyard

Fig 3.13 Maison de Verre, sliding panel detailed section

The Maison de Verre (House of Glass) was designed by ensemblier Pierre Chareau, in collaboration with architect Bernard Bivoet and metalworker Louis Dalbet, between 1928 and 1932. Commissioned by a leading gynaecologist, Dr Dalsace, the house incorporates the doctor's practice on the ground floor, creating a dual-programmed architecture. The design of the Maison de Verre was reconfigured following an elderly tenant refusing to relocate from the top-floor apartment at 31 Rue Saint-Guillaume; this led Chareau to demolish the two lower floors and insert a new steel structure to stabilise the apartment above. The Maison de Verre is aptly named due to its front and rear façades, constructed from 200mm × 200mm × 40mm Nevada-style glass blocks. Internally, Chareau blurred the boundary between architecture and furniture: balustrades double as bookshelves and wardrobes act as walls. Throughout the house, aluminium was used as a component, in small amounts due to lack of availability. Chareau placed it in areas of high wear. For example, aluminium plates were used on the sliding panel separating the Grand Salon and Dr Dalsace's study.



Daily Express Building, London, England: Architect Ellis & Clarke with Sir Owen Williams, 1932

Fig 3.14 Daily Express Building, Fleet Street, London

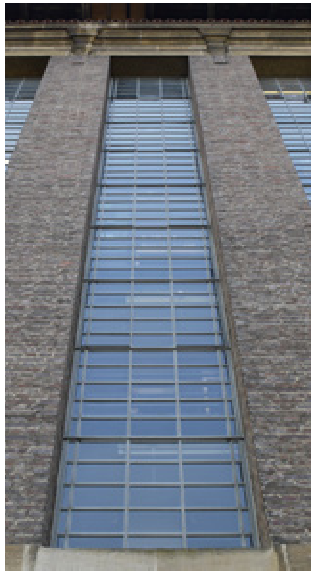
The Daily Express Building was built between 1930 and 1932, a time when almost every major newspaper had an office on Fleet Street in the City of London. This Grade II* listed building is a key example of Art Deco architecture in London. Ellis & Clarke designed the building with engineer Sir Owen Williams. The initial proposal for the building saw it clad in Portland stone, but this was prevented by site constraints and the need to have printing presses running in the basement. Instead, the building was clad in Vitrolite panels (vertically toughened glass) with aluminium alloy strips framing the flat and curved glass panels (one of the first uses of vertically toughened glass in the UK). Thus, the cladding of the Daily Express Building is an example of proto-curtain walling. The spectacular entrance lobby designed by K. Atkinson has an unusual aluminium fluted canopy. The inside panelling, balustrades, handrails, pilaster and beam casings were also all formed in aluminium.

Fig 3.15 Aluminium leaf on the recessed ceiling in the entrance lobby of the Daily Express Building

University of Cambridge Library, Cambridge, England: Architect Sir Giles Gilbert Scott, 1934

The University of Cambridge Library was established before 1416; however, it is the current main building designed by Sir Giles Gilbert Scott and located next to Clare College that is relevant to this research. Constructed between 1931 and 1934, this impressive brick-built library is glazed exclusively with aluminium windows. Some suggest it is reminiscent of Sir Giles Gilbert Scott's industrial architecture that includes Bankside Power Station in London, which is now Tate Modern. The central tower of the library is 48m high. The anodised aluminium windows, with single clear glazing, were manufactured by James Gibbons in Wolverhampton and are still in good working order. In the offices the windows have had openable secondary glazing added to improve their thermal performance. In the library's circulation space the windows are in their original condition from the 1930s.

Gilbert Scott used the same window manufacturer to produce the anodised aluminium windows of the New Bodleian Library in Oxford (see p. 42). It has only been possible to test the finishes of the library in Oxford; for further information, see Chapter Six.



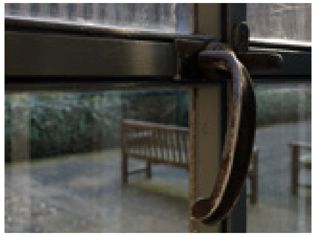


Fig 3.16 [above right] Anodised aluminium windows of the University of Cambridge Library, photographed 2013

Fig 3.17 [right] Internal anodised aluminium window frame with an original brass handle, photographed 2013

Fig 3.18 [below] University of Cambridge Library, photographed 2013

Early Catalogue of Extrusions: Designer Jean Prouvé, 1937

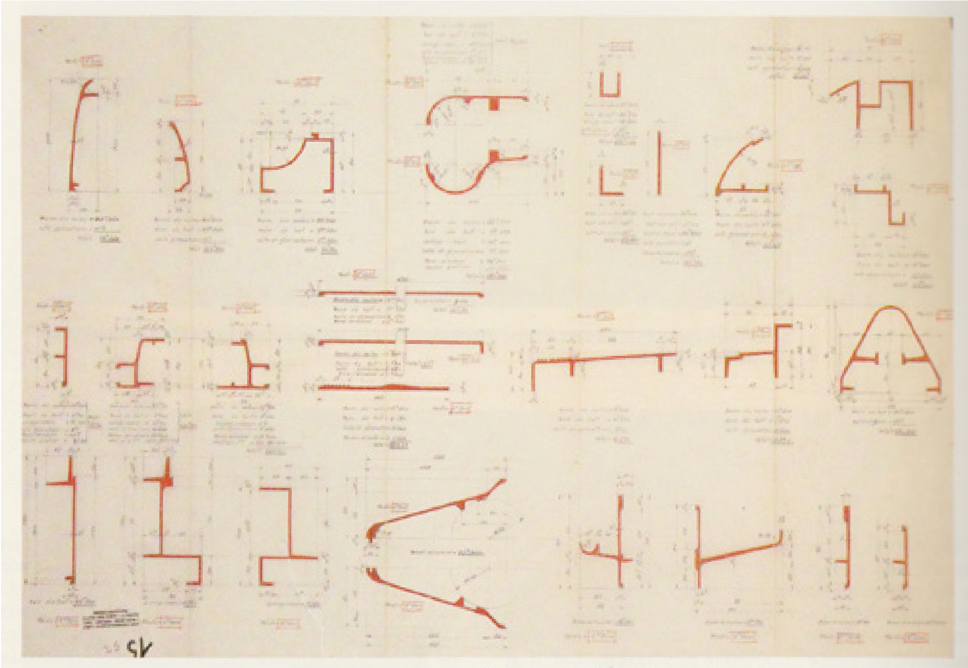


Fig 3.19 Jean Prouvé's drawing of extruded profiles, 1937

This Jean Prouvé drawing on tracing paper from 1937 shows a range of extruded profiles, all open sections, which he designed for the French Embassy in Ottawa, Canada. At this time in his workshop Prouvé was primarily using press brakes to form sheet steel and aluminium sheet into cladding and proto-curtain walling – see, for example, his pioneering design for the Maison du Peuple in Clichy, France, completed in 1939.

This early engagement by Jean Prouvé with extrusions is included here to illustrate the development of technology and technique and not as a complete case study.

New Bodleian Library, Oxford, England: Architect Sir Giles Gilbert Scott, 1940

In the heart of Oxford's historic centre, the New Bodleian Library, designed by Sir Giles Gilbert Scott, was built as a result of the Bodleian Library reaching full capacity. The New Bodleian Library was constructed on a spacious site to the north of the Bodleian Library between 1936 and 1940. The windows were fabricated and anodised by James Gibbons, probably in 1938, and installed during 1939. It was first used for military purposes during the Second World War. The library's Grade II listing recognises the high quality of Gilbert Scott's design. He used anodised aluminium windows throughout the library – a prominent architectural detail. Architect WilkinsonEyre has recently refurbished the library with a significantly improved and fully accessible entrance sequence. It reopened in March 2015 as the Weston Library, named in honour of the £25 million donation given in March 2008 by the Garfield Weston Foundation. The windows have only been cleaned and re-glazed as part of this project. The anodising was tested during 2013 as part of this research; for further information, see Chapter Six.

Fig 3.20 Anodised aluminium window of the New Bodleian Library, Oxford

Fig 3.21 [left] East elevation of the New Bodleian Library, Oxford

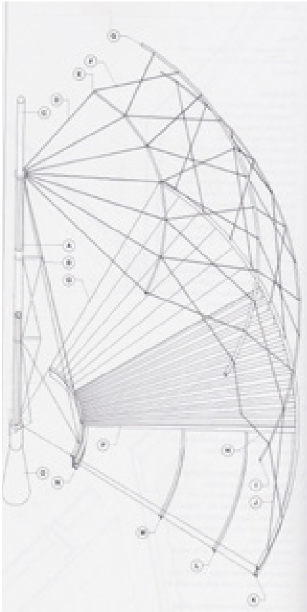


Fig 3.22 [right] Dymaxion House wall section showing the frame only

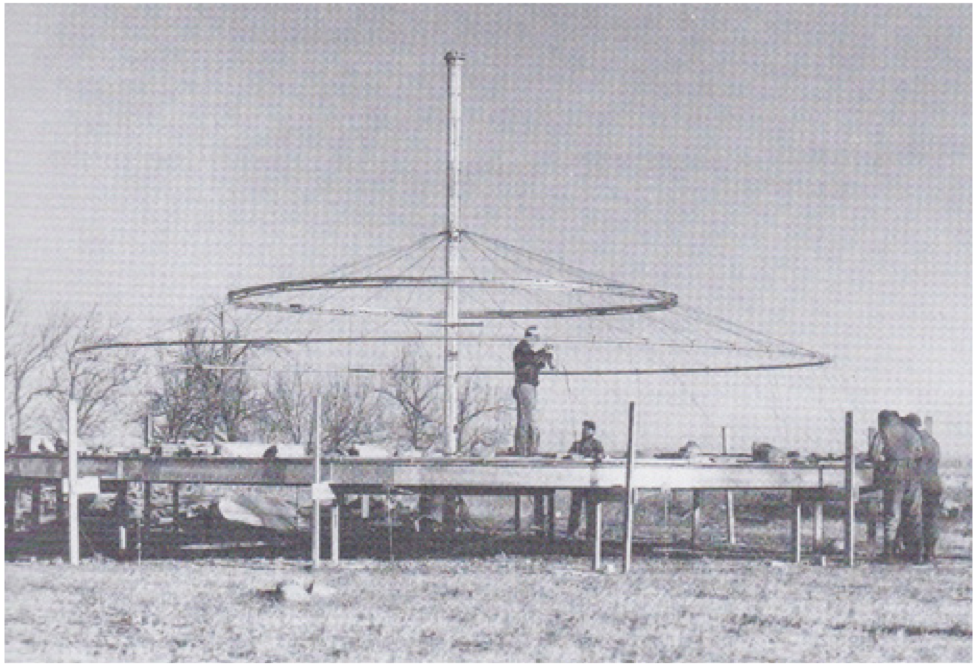


Fig 3.23 [right] Dymaxion House under construction

Dymaxion House, Dearborn, Michigan, USA: Engineer Richard Buckminster Fuller, 1946

Now located at the Henry Ford Museum & Greenfield Village, Michigan, the Dymaxion House, designed by engineer Richard Buckminster Fuller, was completed in 1946 at Wichita. It was part of a series of dymaxion experiments dating back to 1927. Buckminster Fuller considered lightweight (minimal mass) to be the key factor in the design of architecture.

Buckminster Fuller applied four key criteria to the design of the Dymaxion House at Wichita:

1. Achieve minimum weight by the minimum use of material.
2. Reduce wind loading by shape and concealed detailing.
3. Achieve a maximum enclosure of volume with a minimum surface.
4. Apply fine tolerances necessary in metal-based assemblies.[1]

Therefore, the Dymaxion House makes extensive use of aluminium extrusions as framing and aluminium sheeting as cladding. This is combined with stainless steel rods in the form of a masted circular structure, which is internal to the cladding.

Note

1 E. R. Ford (2003), *Details of Modern Architecture, Volume 2: 1928 to 1988*, The MIT Press, Cambridge, MA, pp. 248–255.

Aluminium Bungalow, Museum of Welsh Life, St Fagans, Wales: Aircraft Industries Research Organisation on Housing [AIROH], 1948

Resulting from a central government initiative in 1944 to bridge the anticipated post Second World War housing shortage, one system of prefabricated housing, or prefabs, was developed by the Aircraft Industries Research Organisation on Housing [AIROH]. The AIROH prefab manufactured in 1948 (shown in Figure 3.25) was re-assembled at the Museum of Welsh Life at St Fagans, near Cardiff in south Wales, in 1998. The specific model is a Type B2 AIROH house and it was one of 40 prefabricated three-bedroom homes built by the aircraft industry for Llandinam Crescent in Cardiff. Staff at the Museum of Welsh Life believed this to be the only aluminium prefabricated home still in existence in the UK. However, there is a group of 30 aluminium prefabs in Redditch, which were saved from demolition in 2002. The AIROH prototype house was built at the factory of the Bristol Aircraft Company (BAC), one of the members of the AIROH.[1] Designed to take up spare capacity in the aircraft industry factories that had once assembled Spitfires, the AIROH prefabs were produced in four sections, which were bolted together on site. In total, 54,500 AIROH houses were manufactured, about one third of all post Second World War prefabs. These modest detached houses with gardens proved very popular and far exceeded their predicted life expectancy of ten years. Why were these homes given such a short life expectancy?

Fig 3.24 Second segment of an AIROH aluminium bungalow being craned into position on brick foundations at the aluminium *From War to Peace* exhibition on 21 June 1945

This was politically expedient as the houses were provided by central government. Under Scottish Building Regulations, the life expectancy of an AIROH prefab was rated as 60 years.[2]

On visiting the AIROH prefab at St Fagans, the only overt aluminium detail is the aluminium canopy that shelters the front and back door from typical wet weather. However, each house used aluminium extensively. Wall panels are aluminium sheets riveted to aluminium extrusions, filled with an aerated cementitious insulation, with plasterboard internal linings. The roof is an aluminium truss, clad inside and out with aluminium sheet. The services, furnishings and kitchen, including cooker and refrigerator, were all installed in the factory. The four sections were placed on modest foundations and were simply and quickly bolted together. The parents of Neil Kinnock, leader of the Labour Party in opposition to Prime Minister Margaret Thatcher in the 1980s, lived in an AIROH prefab. He remembered, 'It had a fitted fridge, a kitchen table that folded into the wall and a bathroom. Family and friends came visiting to view the wonders. It seemed like living in a spaceship.'[3] The AIROH prefabs proved to be durable and popular homes.

Notes

1 BAC also designed and assembled aluminium-based schools. They had completed 57 post-war schools by 31 July 1949. In 1951, Whitmore Park Primary School was hailed as the 'largest aluminium school' yet built, cited in B. Russell, *Building Systems, Industrialization and Architecture*, Wiley, London, pp. 226–228 .

2 B. Vale (1995), *Prefabs: A History of the UK Temporary Housing Programme*, E & FN Spon, London, p. 16.

3 Quoted in M. Pawley (1993), *A dose of morphine: the rise and fall of public sector housing*, Frieze, 10, available online at www.frieze.com/issue/article/a_dose_of_morphine (accessed December 2013).

Fig 3.25 AIROH aluminium prefabricated house, St Fagans, photographed 2013

Equitable Building, Portland, Oregon, USA: Architect Pietro Belluschi, 1948

Based on his '194X' competition design for an office building overtly inspired by aircraft technology, Pietro Belluschi's Equitable Building, in Portland, Oregon, has aluminium cladding and curtain walling. For the cladding, he originally wanted to use an all-aluminium composite panel with a honeycomb core. The completed project has cast aluminium panels, which are 4.75mm or 3/16" thick. The extruded aluminium T-section and angle curtain walling houses double-glazing, which was a very unusual specification for this time.

Fig 3.26 Equitable Building, Portland, architect Pietro Belluschi

Fédération Nationale du Bâtiment Offices, Paris, France: Architect Gravereaux & Lopez, Façade Design Jean Prouvé, 1949

In 1949, Jean Prouvé designed unitised aluminium curtain walling, with a module width of 1,450mm and a weight of only 92kg, for the Fédératon Nationale du Bâtiment Offices in Paris. When Brookes & Stacey designed unitised curtain walling for an office building in the City of London in 1989 (see pages 210–213), this practice of full prefabrication was still seen as ground-breaking, although it has since become the norm for high-quality curtain-walling projects on tight urban sites.

Fig 3.27 Unitised aluminium curtain walling being installed on Fédération Nationale du Bâtiment Offices, Paris

Johnson Wax Research Tower, Racine, Wisconsin, USA: Architect Frank Lloyd Wright, 1950

The Johnson Wax Research Tower, designed by Frank Lloyd Wright and completed in 1950, was the second phase of the Johnson Wax Buildings at Racine, Wisconsin. The Administration Building with its Great Workroom with its dendriform-shaped concrete columns was occupied in 1939. The roof lights of the Great Workroom were assembled from Pyrex tubes and sealed with a site-applied sealant or caulking. Throughout the project Lloyd Wright believed that: 'If every part of the building were to contribute to the unity of the whole, stock details would not suffice.'[1]

The Johnson Wax Research Tower is clad in a pioneering tubular glass and aluminium glazing system. This assembly comprises borosilicate toughened glass tubes, manufactured by Pyrex; the glass tubes are supported by aluminium racks with wire restraints. The junctions between the horizontally laid glass tubes are sealed with extruded ultraviolet-resistant vinyl gaskets (trade name Koroseal) that have two voids to aid the compressive seal. With this inventive walling assembly, Lloyd Wright anticipated the development of curtain walling that would take place during the 1950s by the use of glass units, gaskets and preformed aluminium support systems.

Notes

1 J. Lipman (1986) *Frank Lloyd Wright and the Johnson Wax Buildings*, Rizzoli, New York, p. 73.,

2 Ibid., p.152.

Fig 3.28 Johnson Wax Research Tower: tubular glazing system, 1939

Fig 3.29 Johnson Wax Research Tower

UN Secretariat Building, New York, USA: Executive Architect Harrison & Abramovitz, 1950

The aluminium curtain walling of the UN Secretariat Building is described as the first curtain walling in New York, as it was installed before Lever House (see pp. 52–53). The site was cleared in 1947 and construction started in 1948; the UN Secretariat Building was completed in 1950, and the complete facility opened in 1952. The Advisory Board of architects for the UN Secretariat Building consisted of N. D. Bassov (Soviet Union), Gaston Brunfaut (Belgium), Ernest Cormier (Canada), Le Corbusier (France), Liang Seu-Cheng (China), Sven Markelius (Sweden), Oscar Niemeyer (Brazil), Howard Robertson (UK), G. A. Soilleux (Australia) and Julio Vilamajó (Uruguay), with Harrison & Abramovitz acting as executive architects. This team produced a series of designs from which Le Corbusier's and Oscar Niemeyer's design proposals were merged together to create a hybrid project named 42G. The UN Secretariat Building was refurbished between 2007 and 2012, including full replacement of the curtain walling, which retains the original appearance yet is much more energy efficient.

Fig 3.30 UN Secretariat Building, New York, photographed 2013

H. J. Heinz Co. Warehouse and Vinegar Plant, Pittsburgh, Pennsylvania, USA: Architect Skidmore, Owings & Merrill, 1952

The Warehouse and Vinegar Plant forms a 1952 extension of Heinz's existing Pittsburgh production complex. The Vinegar Plant is clad in a crisp extruded aluminium curtain-walling system with opening sliding pivot windows. All of the window and curtain-walling sections are open extrusions with extruded aluminium I-beam mullions. This project, designed by Skidmore, Owings & Merrill, is considered 'an important achievement in modern industrial architecture'.[1]

Note

1 E. Danz (1962), *Architecture of Skidmore, Owings & Merrill, 1950–1962*, Monacelli Press, New York, p. 26.

Fig 3.31 End elevation of the Vinegar Plant with covered loading deck

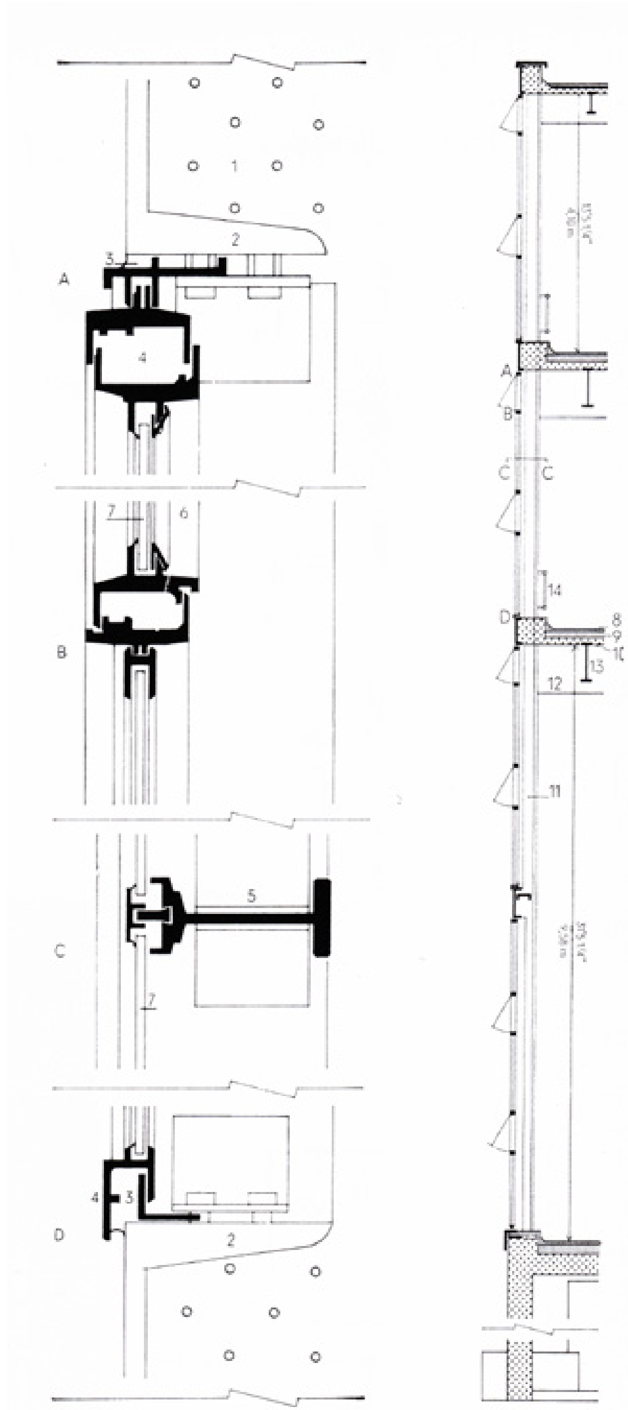
Fig 3.32 Detail of the Vinegar Plant façade, crisply detailed aluminium curtain walling

Fig 3.33 Detail of the Vinegar Plant façade – aluminium sliding pivot windows

Fig 3.34 Vertical section through the exterior wall

A detail of position A
B detail of position B
C horizontal section, detail of position C–C
D detail of position D

1 concrete
2 steel section
3 non-setting sealing compound
4 aluminium sash
5 vertical aluminium mullion
6 ventilating sash
7 hammered heat - and glare-reducing glass
8 cement finish
9 concrete fill
10 reinforced concrete floor
11 steel column
12 main girder
13 secondary girder
14 bumper rail to protect glass windows



Lever House, New York, USA: Architect Skidmore, Owings & Merrill, 1952

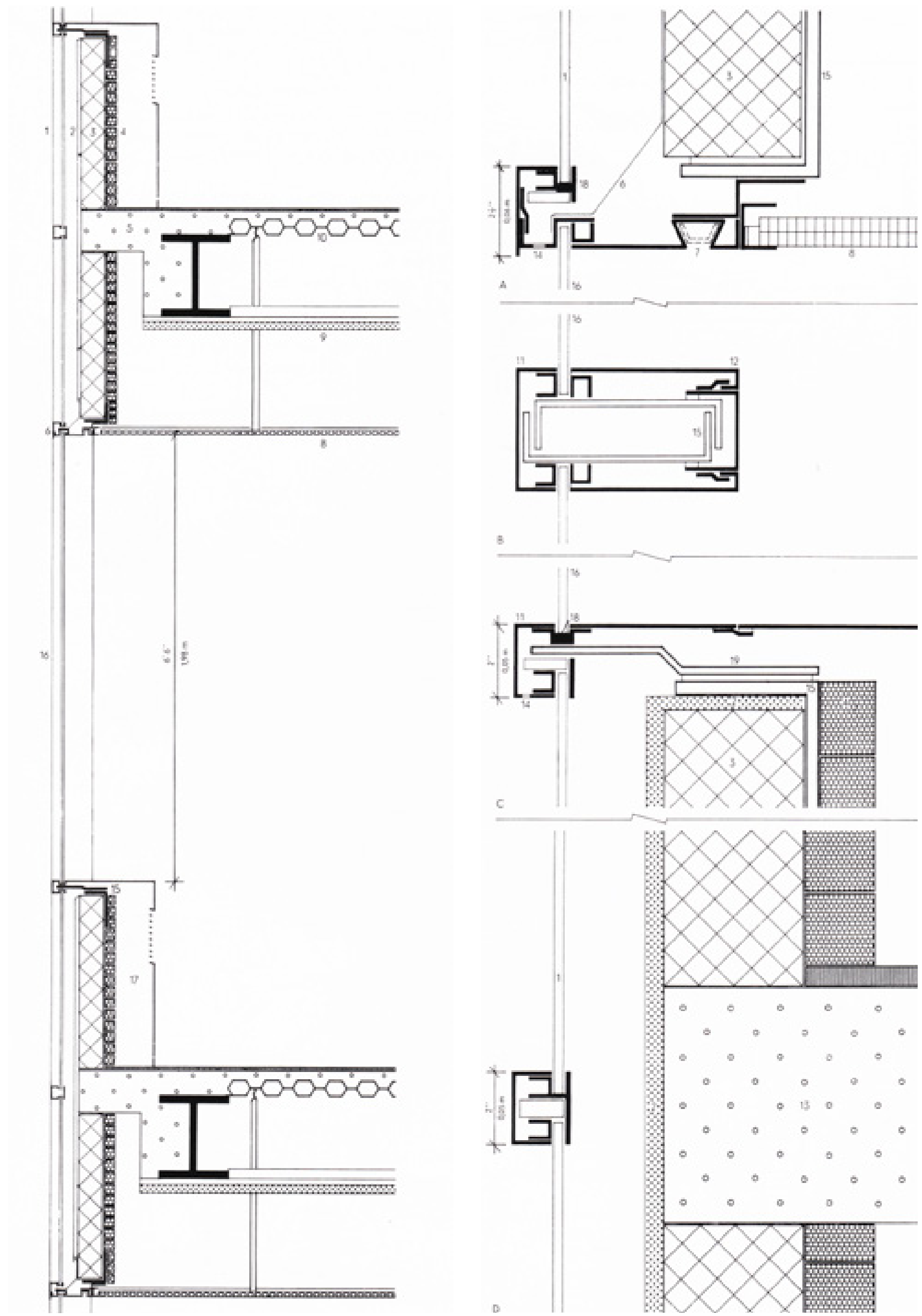
This new office for the British soap manufacturers Lever Brothers, designed by Skidmore, Owings & Merrill, was built on Park Avenue, New York, between 1951 and 1952. Gordon Bunshaft was the lead architect and partner in charge of this project. The podium and office tower are all clad in dark green spandrel panels with clear glass viewing panels all supported by a bespoke stainless steel curtain walling. This curtain walling demonstrates a close collaboration between the architect and the specialist sub-contractors who made and installed the curtain walling. Although the curtain walling was only single glazed, the norm up to the late 1970s, it is interesting to note the use of fire-resistant foam glass insulation. The original curtain walling was replaced with a double-glazed aluminium curtain-walling system under the direction of Skidmore, Owings & Merrill in 2001. Alcoa currently has its world headquarters in this iconic Manhattan building.

Fig 3.35 Lever House, New York: view from Park Avenue, east elevation – extreme lightweight construction emphasised by the set-back of upper floors and separation of horizontal slab and vertical tower

Fig 3.36 Night view of Lever House

Fig 3.37 [right] Vertical section through the exterior wall

- A vertical section through curtain wall
- B horizontal section through a mullion
- C vertical section through lower curtain wall
- D vertical section at floor level
- 1 green spandrel glass
- 2 cement parging
- 3 concrete blocks
- 4 cellular glass insulation
- 5 concrete
- 6 weephole baffle
- 7 recess for ventilation
- 8 acoustic tile ceiling
- 9 fireproofing
- 10 cellular steel decking
- 11 stainless steel (16 gauge)
- 12 stainless steel (16 gauge)
- 13 concrete floor slab
- 14 weephole
- 15 steel angle reinforcement
- 16 heat-absorbing fixed plate glass
- 17 window induction unit
- 18 attachment steel



Evolution House, Kew Gardens, London, England: Architect S. L. Rothwell, 1952

Fig 3.38 Evolution House, Kew Gardens, London

The Australian House, now known as Evolution House, was a gift from the Australian Government to Kew Gardens. Originally designed to accommodate plants previously stored in the Temperate House, since 1995 Evolution House has housed the Evolution exhibition, which charts the evolution of plants. In 2011, Evolution House was Grade II listed by English Heritage. It was designed by S. L. Rothwell, of the Chief Architects Division of the Ministry of Works,[1] with consultant engineer J. E. Temple.[2]

Rothwell and Temple's design is an early post Second World War use of aluminium in a horticultural building of a significant scale. Evolution House represents an efficient glasshouse design with integrated ventilation and heating and a carefully considered, integrated cleaning system. Rectangular on plan, and with a mansard roof, the glasshouse is constructed of ten bays measuring 27.4m × 15.9m (90′ × 52′), is 10.2m (33′ 6″) in height and covers an area of 434.7m^2 (4,680ft^2). The main frame consists of 11 arches of lattice construction, with 203 × 102mm (8″× 4″) uprights and angle purlins. The end bays are braced; the glazed curtain wall is bolted to the frame and uses standard window sections. Evolution House was constructed by the Crittall Manufacturing Company Ltd.

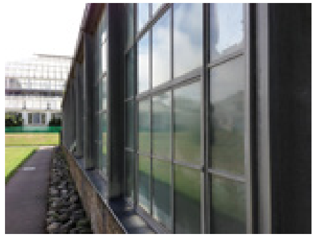


Fig 3.39 Detail of the aluminium façade of Evolution House, Kew Gardens

Evolution House is constructed of H10-WP aluminium alloy extrusions on a prefabricated galvanised base frame, set on a plinth of reused London stock bricks capped with a slate cill course. Each bay is ventilated with horizontally opening side windows and remote-operated (mechanical) clerestory windows. Entrances, in the end bays, have moulded Art Deco aluminium architraves.

The English Heritage (now Historic England) listing states:

> Noted for its lightweight and resistance to corrosion, aluminium was particularly useful to horticulture. The annual report of the Agriculture and Horticulture Research Station for 1948 referred to 'two small, aluminium greenhouses, for work on radio-active tracer elements and growth regulating substances', which were completed that year, while in 1950, *Gardening Illustrated* advertised 'Crittall Rustless Greenhouses'. Aluminium was used for whole buildings only after 1945, making this an early and rare example of an aluminium glasshouse of this period and of this scale.[3]

However as this book reveals aluminium had been used in architecture since 1895.

Using a cleaning spray system internally and with rails to attach ladders externally, Evolution House represents the integration of structural form, materials and architectural expression in an early post Second World War aluminium-framed glasshouse; its aluminium structure is of note in representing an early and intact example of complete prefabrication. Whilst the essential components of the window system were a proprietary Crittall aluminium system, both the primary frame and much of the detailing, jointing and abutment or assemblage connections would seem to be of a bespoke nature. Evolution House has remained intact without any significant weathering defects, discolouration or failure, either in material finishes or the primary frame, due to highly successful bespoke detailing, material choice and construction quality.

Notes

1 The Ministry of Works was formed by the UK Government in 1943 and renamed the Ministry of Public Building and Works in 1962. In 1970, it was merged into the Department of Environment. In 1972, the works functions, including architects, were privatised in the form of the Property Services Agency, which was subsequently abolished in 1996.

2 Sourced from the English Heritage listing, list entry number: 1401475, dated 9 May 2011.

3 Ibid.

General Motors Technical Center Styling Studios & Shop, Warren, Michigan, USA: Architect Eero Saarinen, 1952

The General Motors Technical Center was designed by Eero Saarinen as a campus of three-storey buildings arranged around the five staff groupings of the company: research, engineering, process development, styling and service. Saarinen believed that architecture should be expressive of its time and technology. Based on technology developed by General Motors, the Technical Center is clad in the world's first gasketed curtain walling on extruded aluminium mullions and based on a 5-foot module (1,524mm). Polychloroprene (trade name neoprene) had been invented in the 1930s by DuPont. The first well-documented installation of neoprene gaskets was the assembly of the Harrisburg West Interchange Turnpike Booths in Pennsylvania, in 1949. In 1985, Alan Brookes noted that 'The gaskets on this project are still providing sound weathering and structural retention'.[1]

The first block of the Technical Center, constructed in 1951, soon leaked as the sealant caulking failed to adhere to either the aluminium framing or the panelling, which was glass and vitreous enamel. General Motors, based on its experience with gaskets in the automobile industry, applied its resources to solving the problem and produced a weather seal similar to that used on the Harrisburg Turnpike booths.[2] This zipper-type gasket allowed the glass to be accurately positioned within the aluminium framing before pressure was applied via the gasket. The gaskets appear to have been butted and glued; vulcanised corners were a later development. These gaskets were not continuously stretched around a curved corner as in a car windscreen. In total, 4,600m of neoprene gaskets were installed at the Technical Center. Eero Saarinen's goal was 'an architecture of precision' to honour the vehicles mass-produced by General Motors.[3]

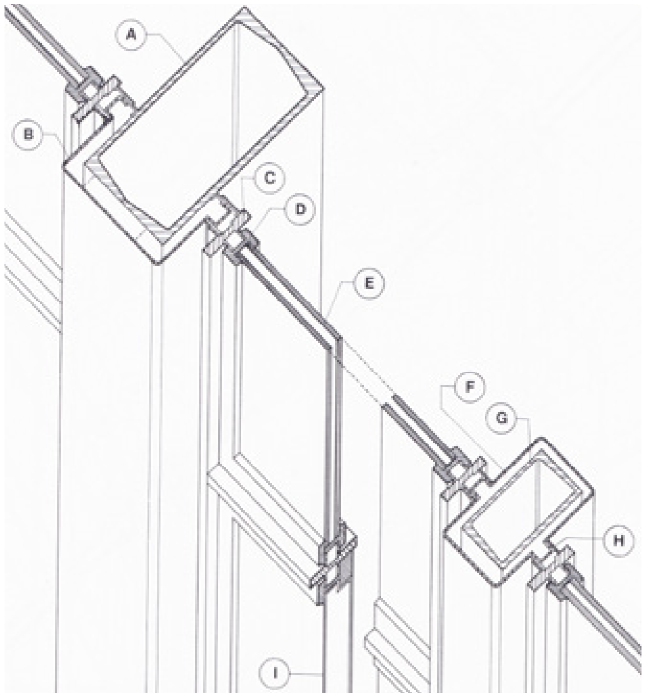


Fig 3.40 General Motors Technical Center: detail of the curtain wall

A 5 3/4 ×12" steel tube column from two channels. The large tube supports the beams of the floor above.

B 1/8" extruded aluminium cover with black porcelain enamel finish attached with hanger clip. This protects the steel from rust while providing space for insulation, although only some of the buildings at GM insulated the columns.

C extruded aluminium mullion.

D extruded rubber gasket. This was later changed to neoprene for additional strength.

E 1" insulating glass

F 1/8" aluminium cover

G 3 1/4 × 6" steel tube. This tube is non-structural and serves only to support the curtain wall.

H aluminium closure fastened with stainless steel oval-headed screws.

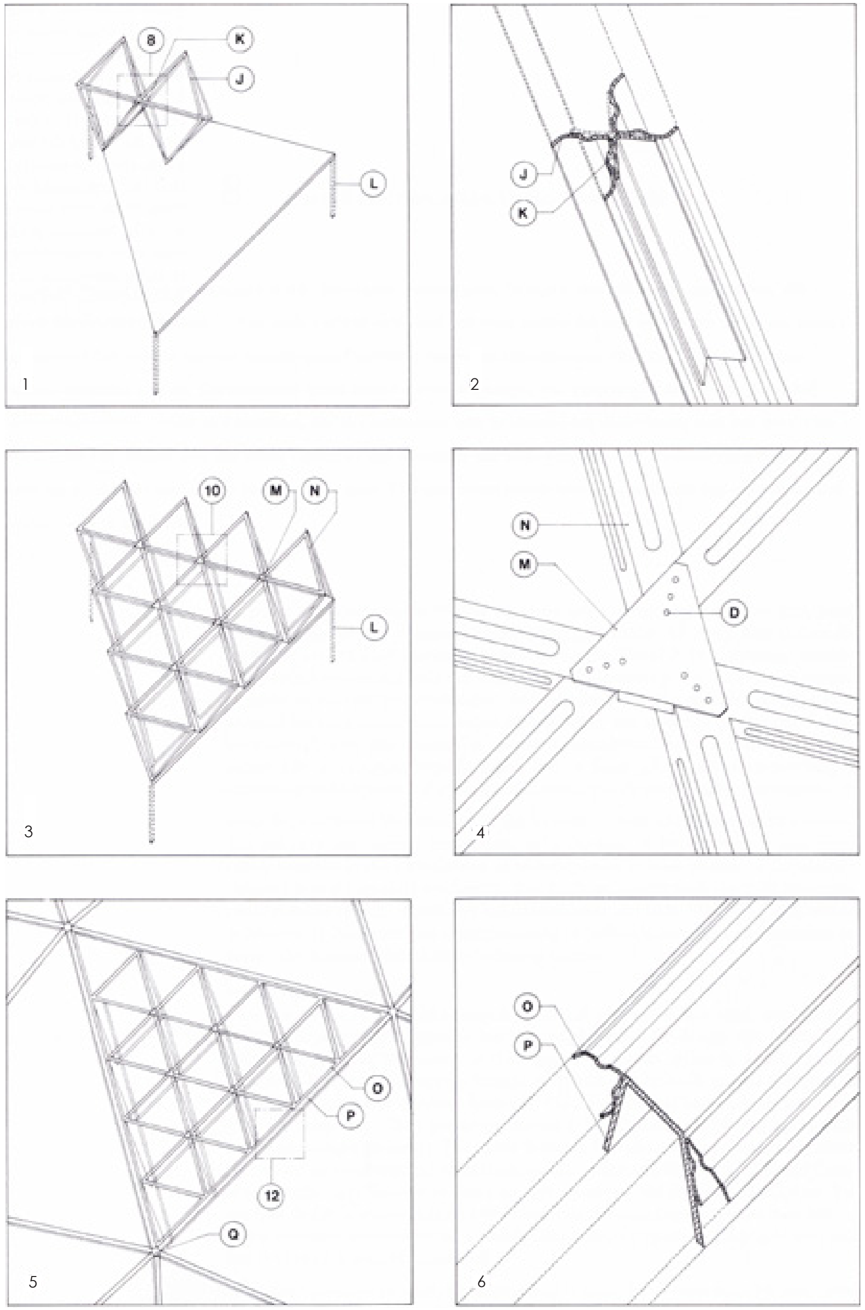
I insulated porcelain-faced sandwich panel attached to aluminium mullion with gaskets.

Fig 3.41 Cadillac Series 62: Saarinen's goal was an 'architecture of precision' to honour the vehicles mass-produced by General Motors

Notes

1. A. Brookes (1985), *Development and use of gaskets in cladding systems*, Roofing, Cladding & Insulation, February, pp. 29–33.
2. M. Stacey (2001), *Component Design*, Architectural Press, Oxford, pp. 43–44.
3. Cited in P. Serraino (2006), *Saarinen*, Taschen, Cologne, p. 34.

Aluminium Geodesic Dome, Ford Rotunda, Dearborn, Michigan, USA: Engineer Richard Buckminster Fuller, 1953



Richard Buckminster Fuller's first large-scale geodesic dome was constructed in 1953 on Albert Kahn's earlier Rotunda at the Ford Plant at Dearborn, Michigan, which dates from 1933. The structure of the dome was formed from press-braked aluminium sections, which were riveted together to form equilateral triangles; these were then linked to form octahedrons. Ten octahedrons were joined together to form truss segments. The dome was not a pure sphere and the dimensioning of the struts was quite complex. The dome was covered in polyester resin skin. The dome took inspiration from both aircraft manufacture and nature. It was destroyed by a fire in 1960.

Fig 3.42 [left] Key stages in the assembly of the geodesic dome on the Ford Rotunda

steps 1–2

Octahedrons are joined with aluminium angle correctors.

- J 120° strut at edge of octahedron. The 70° struts are all at the top and bottom, while the 120° struts are all internal.
- K aluminium angle connector to hold octets together.
- L large jig table to form truss.

steps 3–4

Ten octahedrons are joined to form triangular octet truss section. The voids between the octahedrons are tetrahedrons, hence the name octet.

- M triangular gusset plate.
- N 70° aluminium strut top of octet.

steps 5–6

The truss section is connected to the channel frame.

- O 70° aluminium strut at edge of triangular truss.
- P aluminium channel.
- Q cast aluminium hub. Additional struts are added when in place to complete the triangular section.

Fig 3.43 [above right] Ford Rotunda

Fig 3.44 [right] Aluminium geodesic dome

Wallspan, England: Williams & Williams, 1953

Williams & Williams' Wallspan system, based on extruded aluminium sections, has been described by David Yeomans as the UK's first curtain-walling system.[1] It was launched in 1953 and, judging by this 1955 advertisement in *Punch* magazine, Figure 3.45, speed of erection was one of its main selling points.

Note

1 D. Yeomans (1998), *The pre-history of the curtain wall*, Construction History, Vol. 14, p. 78

Fig 3.45 Wallspan curtain-walling advertisement, *Punch*, 6 April 1955

Punch, April 6 1955 xxix

Whatever the building or the business WALLSPAN

outer walls serve your purpose precisely!

WALLSPAN is the most versatile outer wall construction material in use to-day. Wallspan walls can be built to serve a wide variety of different needs.

In a storage warehouse, Wallspan will give you all the strength and solidity you could ask. In a factory—vastly more daylight with an unusual degree of heat insulation, plus facilities for partitioning, sub-dividing or expanding. In a modern school—the maximum measure of fresh air and sunshine. In a laboratory it could combine special ventilation with rigid requirements in temperature control. *And give you all these things, please remember, at very competitive cost!*

What Wallspan is. Wallspan is a system of vertical and horizontal aluminium alloy members, formed into a grid to carry windows, doors and the glass or other panelling. Wallspan walls give you complete protection against the weather in any climate. The glazing and panelling can be constructed to afford a comfortable working temperature even in extremes of heat and cold.

Beauty with minimum maintenance. Wallspan also offers your architect fresh opportunities in design, with exciting combinations of glass, metal, plastics and other materials. The grid is a non-corroding aluminium alloy. With a suitable choice of panelling, maintenance is reduced to an occasional rub-down by the window cleaners.

Finally, Wallspan walls go up in a matter of *days* to get your building into use much sooner.

WALLSPAN CURTAIN WALLING WILLIAMS & WILLIAMS *RELIANCE WORKS · CHESTER*

You'll be using your building sooner—much sooner—if it has Wallspan walls!

Alcoa Building, Pittsburgh, Pennsylvania, USA: Architect Harrison & Abramovitz, 1953

Fig 3.46 The Alcoa Building's contribution to Pittsburgh's skyline, photographed 2013

This 30-storey office tower in downtown Pittsburgh was designed for Alcoa by architects Harrison & Abramovitz and opened in 1953. *Popular Mechanics* described it as 'the world's first aluminum skyscraper' in December 1953.[1] It is clad in unitised pressed aluminium curtain walling, measuring 1,829mm × 3,658mm (6′ × 12′), which all were pre-glazed. The curved corner aluminium windows rotate for internal cleaning and are sealed by an inflatable gasket. Aluminium was also used extensively in the construction of these offices, from aluminium air-handling ducts to plaster lathes. The curtain walling was the subject of extensive prototypes and full-scale mocks-ups by Alcoa in collaboration with Harrison & Abramovitz. Alcoa considered the building to be a 'thirty-story demonstration of aluminum's usefulness, economy and beauty … showing aluminium to be at once practical and economical in almost every phase of building construction.'[2] The curtain walling, as well as being unitised, is detailed with baffled open joins anticipating the development of rainscreen panels in the 1960s.[3] Inspected by Stephanie Carlisle of KieranTimberlake in the summer of 2013, this project is described as being in remarkably good condition. The possibility of testing the finish on the aluminium is under investigation.

Notes

1 Anon (1953), *Aluminum Skyscraper*, Popular Mechanics, December Vol. 100, No. 6, pp. 86–87.

2 Alcoa, *Aluminum on the Skyline,*(1954), Pittsburgh, p.3 cited in *S. C. Nichols, ed., (2000), Aluminum by Design*, Abarams, New York, p. 104. Note original American spellings have been retained.

3 A. Brookes, (1983), *Cladding of Buildings*, Construction Press, Harlow, p. 199.

Fig 3.47 Detail view, of the untised aluminium curtain walling, photographed 2013

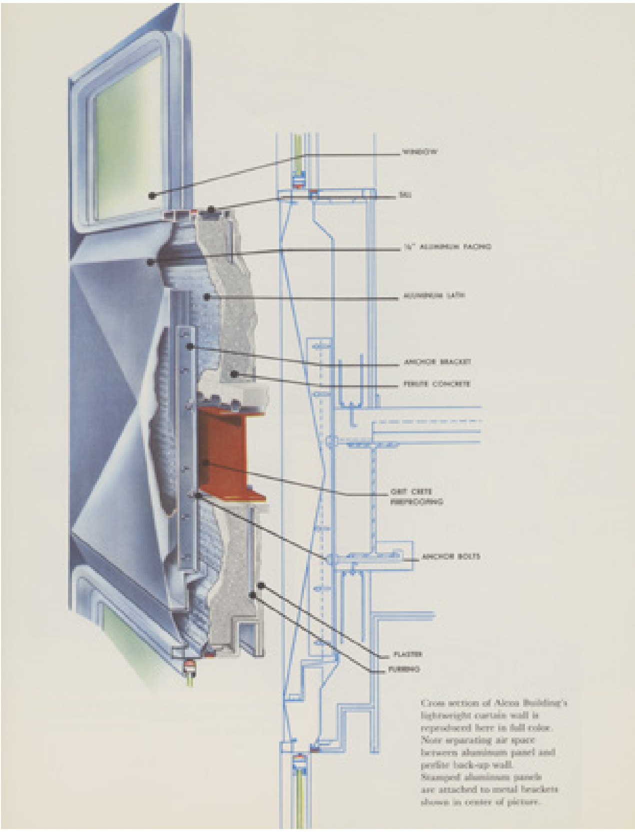
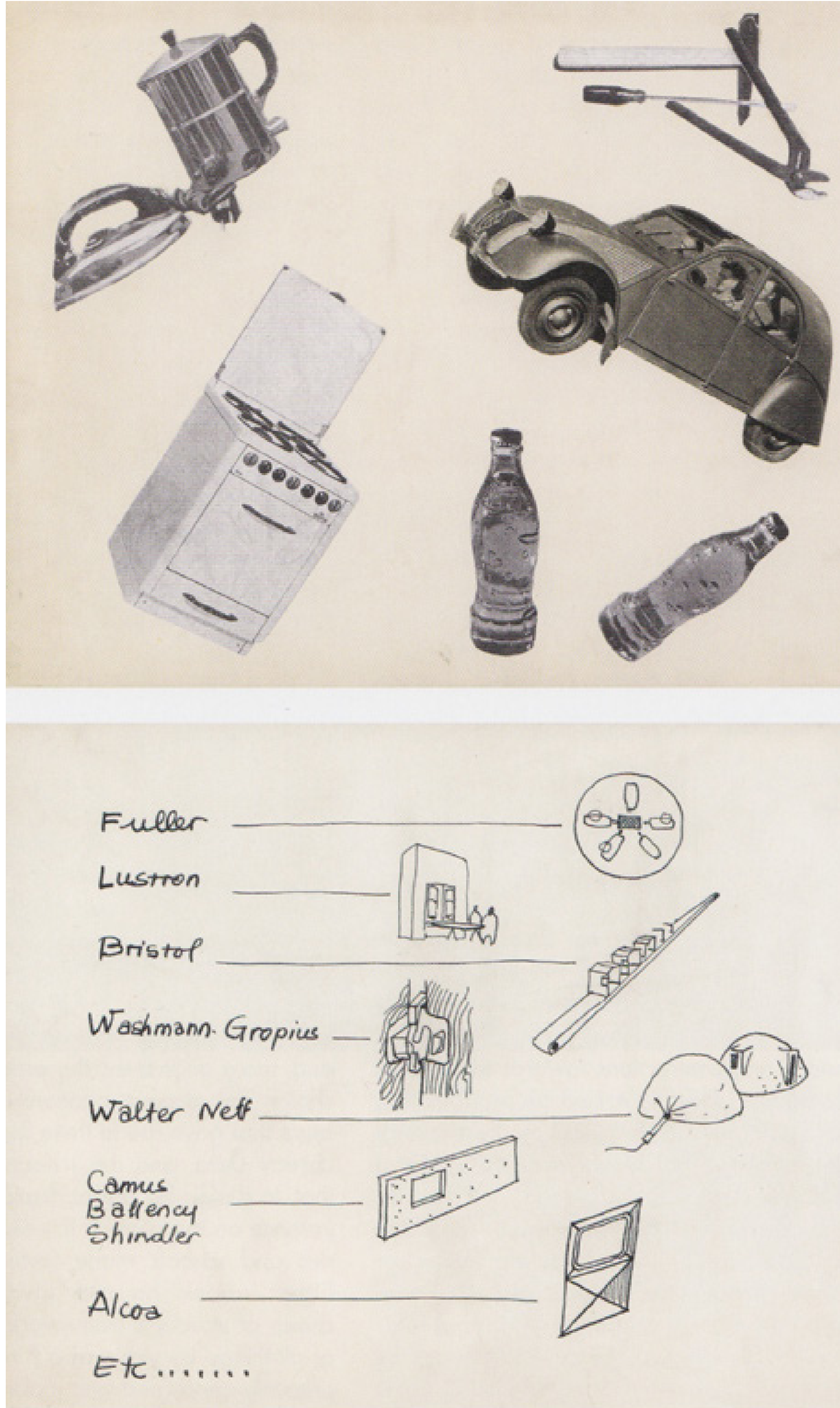


Fig 3.48 Drawing of the unitised aluminium curtain walling of the Alcoa Building

Fig 3.49 The first unitised curtain-walling panel being installed on the Alcoa Building. The panels are secured to flanged fittings bolted to fire-proofed steel beams.

Fig 3.50 [right] Collage and a set of sketches developed by Jean Prouvé for the Congrès Internationaux d'Architecture Moderne [CIAM], Aix-en-Provence, 1953



Meudon Houses, France: Architects Andre Sivé and Henri Prouvé with Engineer/Fabricator Jean Prouvé, 1953

Fourteen experimental houses were built at Meudon under the direction of Andre Sivé. The house designs are attributed to Andre Sivé and Henri Prouvé and have sheet aluminium roofs, aluminium cladding and aluminium mullions, on masonry bases formed from fieldstones. These houses clearly show that the primary collaborator and manufacturer was Henri's brother Jean.

Alex Venacque observes:

> In traditional architecture, tolerances can be comparatively unimportant, but in an architecture dry-assembled from industrially manufactured components, dimensional precision becomes fundamental. This precision takes on all its importance in Prouvé, who was concerned to make erection a lightning operation (less than seven hours for the 57 m^2 Abbe Pierré house, two days for the Meudon Houses, 21 days for the 2000 m^2 of the Aluminium Centenary Pavilion).[1]

The interiors of the Meudon Houses were furnished with chairs and tables by Ateliers Jean Prouvé.

Note

1 A. Venacque, *A Prototypical Legacy*, in A. von Vegesack, C. Dumont D'Ayot and B. Reichlin, B. (eds), *Jean Prouvé: The Poetics of the Technical Object*, Vitra Design Museum, Stiftung GmbH, Weil am Rhein, pp. 360–361.

Fig 3.51 Métrople Type Meudon Houses

Aluminium Centenary Pavilion, Paris, France: Engineer/Fabricator Jean Prouvé, 1954

Jean Prouvé's Aluminium Centenary Pavilion was built in 1954 to celebrate the 100th anniversary of the chemical production of aluminium in France by Henri Sainte-Claire Deville in 1854.[1] Designed as an exhibition hall, the pavilion is a seminal example of Prouvé's preoccupation with aluminium. The pavilion was designed and manufactured to be a 152m-long structure with a frame spanning 15m, spaced at 1.34m centres. The folded-sheet aluminium roof beams were made in three parts, assembled with cast aluminium components, which were attached to extruded aluminium vertical supports, which also serve as mullions. The pavilion was originally erected on the banks of the River Seine. In 1956, the pavilion was disassembled and transported to Lille. Architecture-Studio [AS] carried out the restoration of the pavilion between 1999 and 2000, when it was moved to its current location at Villepinte, Paris. The two relocations of the pavilion verify the logic of a prefabricated modular building system. For further information, see Chapter Four.

Note

1 *Minutes of the Academy of Science*, 6 February 1854, cited in I. Grinberg and J. Plateau (2013), *Aluminium Passion: The Treasure-Trove of the Collection of Jean Plateau – IHA*, Les Éditions du Mécène, Paris, p. 31.

Fig 3.52 Cast aluminium junction between the extruded mullion and fabricated gutter beam of the Aluminium Centenary Pavilion

Manufacturers Hanover Trust Company Bank, New York, USA: Architect Skidmore, Owings & Merrill, 1954

This modest four-storey bank on New York's Fifth Avenue (No. 510) was designed by Skidmore, Owings & Merrill and completed in 1954. The design demonstrates a clear structural logic and precise detailing, which offers transparency by both day and night. Apparently, the client, Manufacturers Hanover Trust Company, wanted to create a prestige bank without rentable floors above that the New York zoning would have permitted. The aluminium curtain walling is a bespoke assembly of open sections, which was still crisp in appearance when inspected and photographed in 2013.

Fig 3.53 Manufacturers Hanover Trust Company Bank, New York: night view from Fifth Avenue, revealing slender aluminium curtain walling

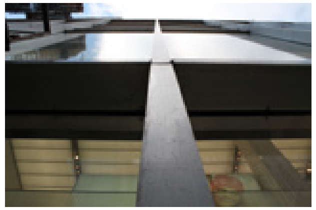


Fig 3.54 Detail of the aluminium curtain wall, photographed 2013

Fig 3.55 510 Fifth Avenue, New York, photographed 2013

Fig 3.56–Fig 3.57 [bottom left and below] Internal views of the aluminium curtain wall, photographed 2013

General Motors Technical Center Styling Auditorium, Warren, Michigan, USA: Architect Eero Saarinen, 1955

The dome of the Styling Auditorium is formed from 9.5mm (3/8″) steel-plate shell, which is a semi-monocoque, as there are internal stiffening angles. Eero Saarinen protected the steel dome with 25mm (1″) thick rigid insulation. It is finished with 2mm (0.081″) thick aluminium shingles, which minimise rainwater penetration, like rainscreen cladding. The insulation is protected from any water ingress by a waterproof membrane below the aluminium cladding. Galvanic corrosion (or bimetallic corrosion) between the steel structure and aluminium cladding is prevented by the use of neoprene washers, ensuring that the two reactive metals, which have a galvanic potential, never come into direct contact.

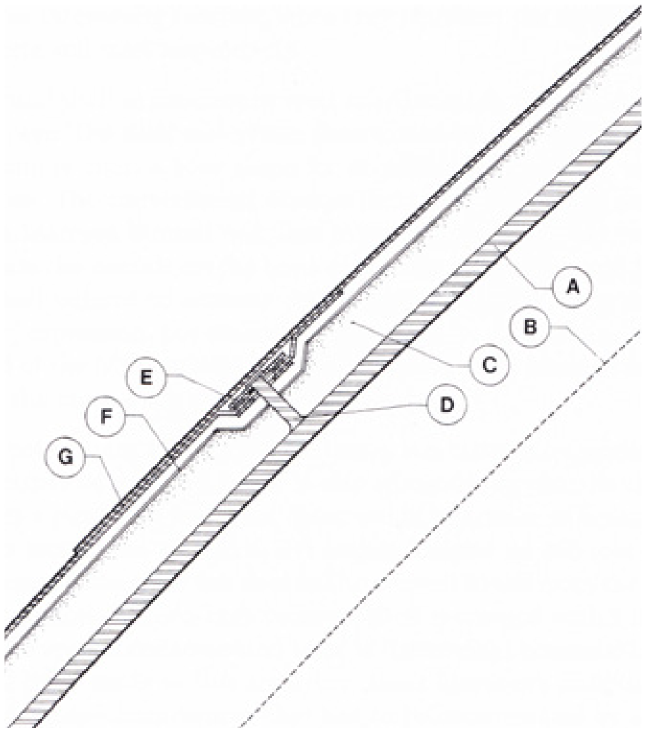


Fig 3.58 General Motors Technical Center Styling Auditorium: section through the external dome façade

- A $^3/_8$″ structural steel plate shell.
- B stiffening angle beyond.
- C 1" rigid insulation.
- D stainless steel stud welded to steel plate.
- E aluminium washer, neoprene washer, and stainless steel washer. The neoprene prevents electrolytic action between aluminium and steel, and the assembly is designed so that these two materials never touch.
- F waterproof membrane to intercept any water that penetrates the roof.
- G aluminium shingle stamped from 0.81″ thick aluminium.

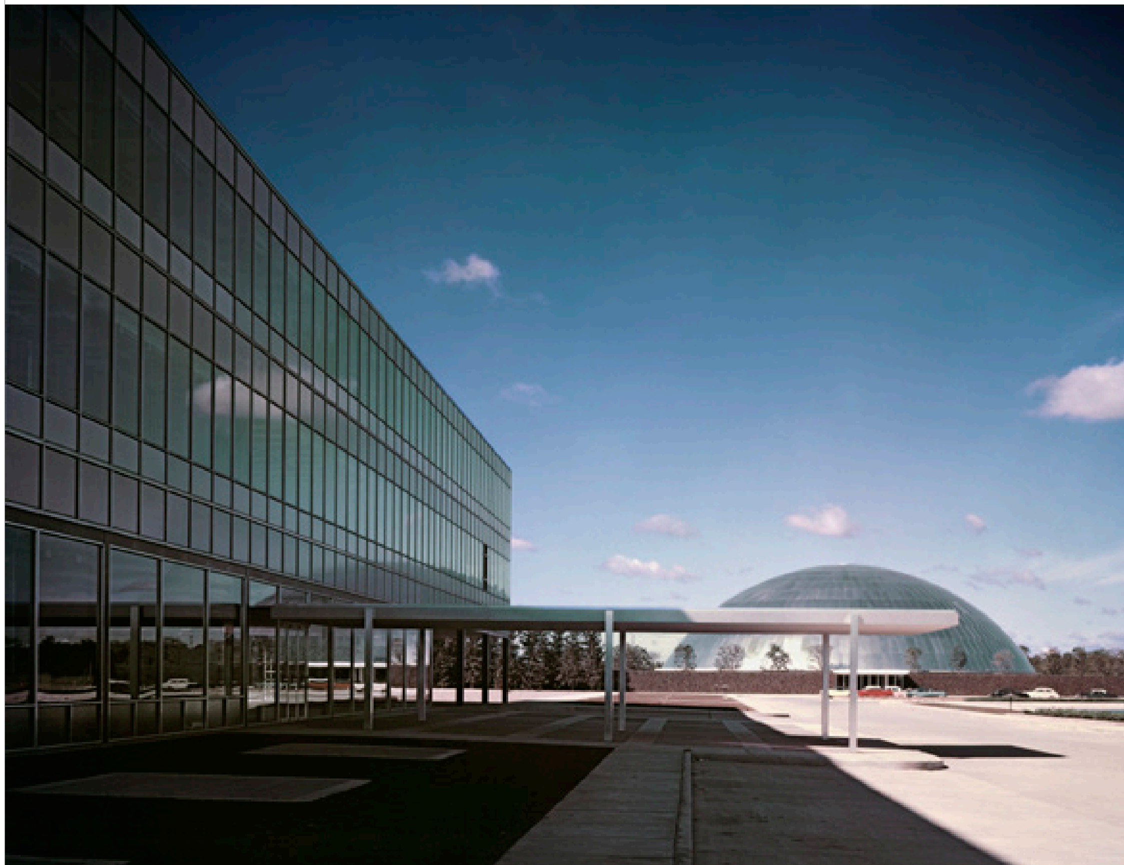


Fig 3.59 General Motors Technical Center Styling Auditorium

Reynolds Metal Company, Richmond, Virginia, USA: Architect Skidmore, Owings & Merrill, 1958

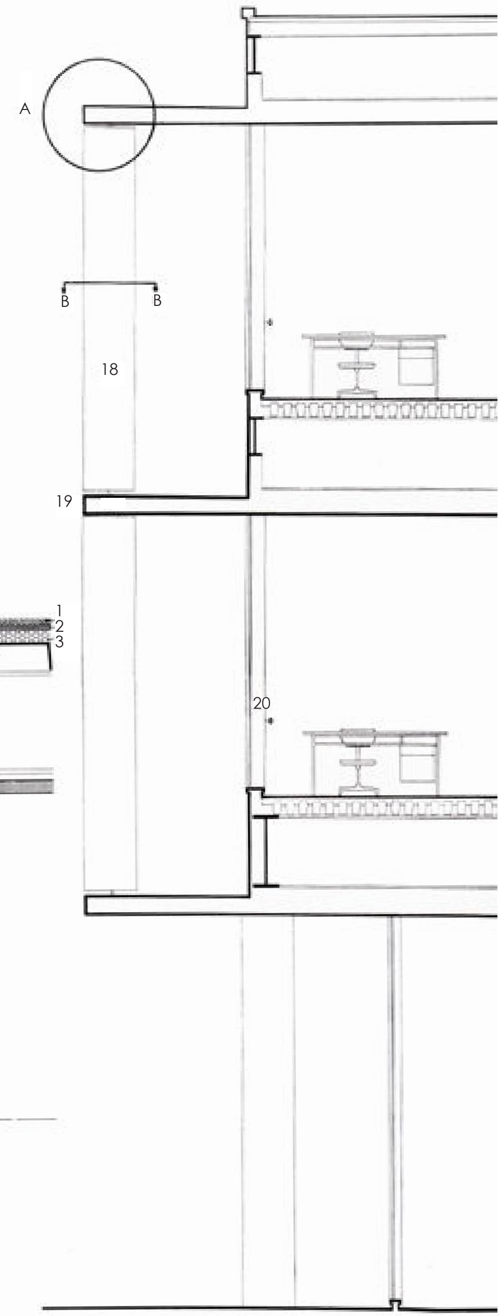
Located five miles north of central Richmond, Virginia, this is an elegantly detailed three-storey office, designed by Skidmore, Owings & Merrill and built between 1955 and 1958. One of the design aims was to showcase the companies expertise in the production of aluminium components. The particular significance of these offices in the history of architecture in the twentieth century lies in the design and specification of vertical and adjustable solar control louvres for the east and west façades in an era when many architectural historians suggest solar control was ignored. The louvres are made up of two matching open aluminium extrusions fixed to an aluminium extruded box section, forming a tapered louvre in cross-section. Skidmore, Owings & Merrill's confidence in designing with aluminium was clearly growing with their consistent use of the material during the 1950s.

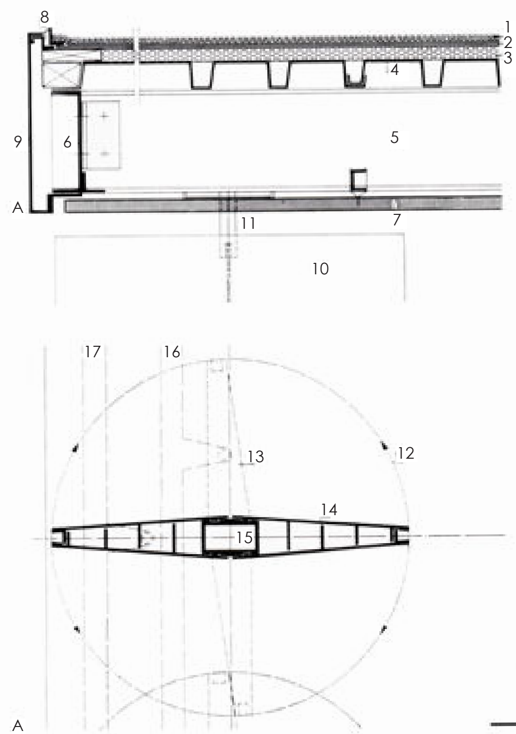
Fig 3.60 Reynolds Metal Company: view of the inner court

Fig 3.61 Detail of the encircling canopy with aluminium sun louvres

A vertical section
B horizontal section
C schematic section

1 marble chips
2 built-up roofing
3 rigid fibre board
4 Reynolds aluminium roof deck
5 cantilevered I-girder
6 longitudinal girder
7 suspended ceiling
8 gasket
9 aluminium flashing
10 aluminium sun-controlled louvre, east and west walls only
11 rotary bearing
12 total louvre movement approximately 175°
13 louvre in closed position
14 louvre in open position
15 louvre composed
16 connecting bar in closed position
17 connecting bar in open position
18 automatic vertical light control
19 horizontal light control
20 glare-reducing glass



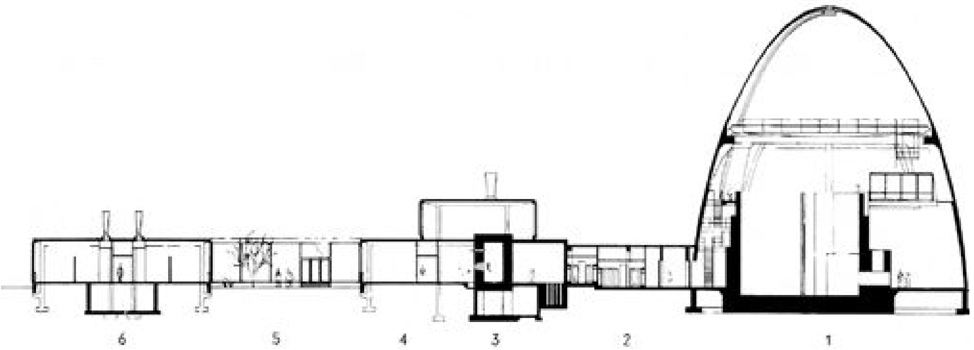


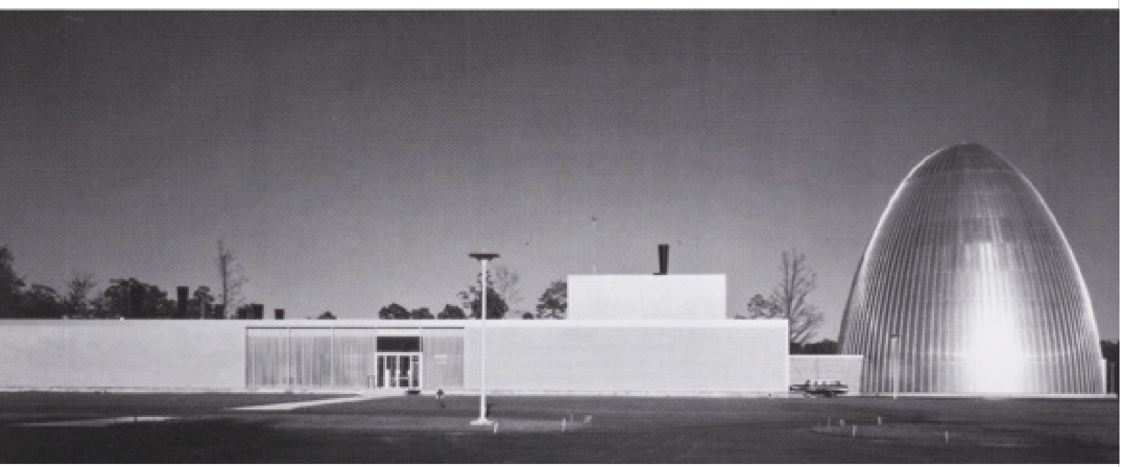
Research Center, Industrial Reactor Laboratories Inc., Plainsboro, New Jersey, USA: Architect Skidmore, Owings & Merrill, 1958

This nuclear reactor research center was designed by Skidmore, Owings & Merrill and completed in 1958. The egg-like dome houses the nuclear reactor. This 26.5m (87′) high shell is formed from a reinforced concrete structure, which is clad with roofing felt, 25mm of insulation and a second layer of roofing felt that is in turn protected by thin sheet aluminium secured with battens.

Fig 3.62 Plainsboro Research Center: comparison of Skidmore, Owings & Merrill's design section and completed project

1 reactor
2 locker rooms
3 hot cells
4 administration
5 court
6 laboratory building





Central Heating and Refrigeration Plant, New York International Airport, USA: Architect Skidmore, Owings & Merrill, 1958

This pavilion housing the Central Heating and Refrigeration Plant (CHR Plant) for New York International Airport (now JFK) is considered by Ernst Danz to be 'a showcase for modern mechanical plant'.[1] Designed by Skidmore, Owings & Merrill and built between 1957 and 1958, the plant is clearly visible through transparent single glazing, which is supported by windows formed from open aluminium extrusions. The elevations are completed and sealed by press-braked aluminium copings.

Note

1 E. Danz (1962), *Architecture of Skidmore, Owings & Merrill, 1950–1962*, Monacelli Press, New York, p. 88.

Fig 3.63 [below] Cross-section through the south glass wall of the Central Heating and Refrigeration Plant

1 exposed steel column
2 longitudinal girder
3 transverse girder
4 concrete slab
5 roofing
6 transverse steel beam to withstand wind pressure
7 painted steel fascia
8 aluminium window section
9 plate glass
10 aluminium coping

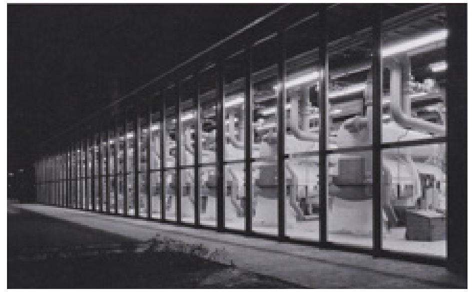
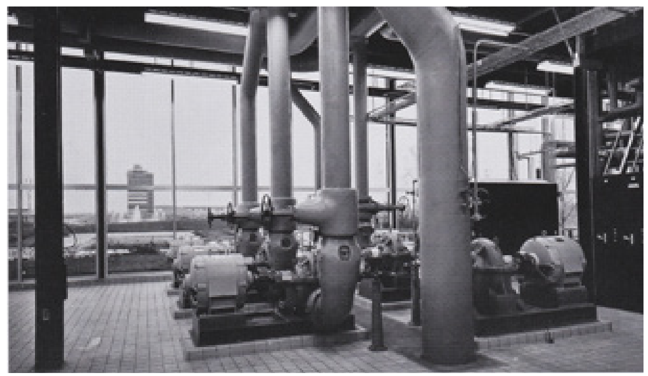


Fig 3.64 [above] Piping systems of the CHR Plant displayed behind the façade

Fig 3.65 [below] Glass-enclosed CHR Plant housing the mechanical equipment

Fig 3.66 [below] View from within the CHR Plant



Jean Prouvé and Compagnie Industrielle de Matériel de Transport [CIMT], 1958: Early Extruded Aluminium Curtain Walling

Until its appointment of Jean Prouvé in 1957, Compagnie Industrielle de Matériel de Transport [CIMT] specialised in the design of railway carriages. CIMT bought out Construction Jean Prouvé in this process. Primarily based on his experience of designing structural aluminium extrusions for the Aluminium Centenary Pavilion, Prouvé designed a series of extruded aluminium curtain-walling sections for CIMT. Catherine Coley observes that 'after 1958 the CIMT–Jean Prouvé duo became the leader in lightweight façade construction for school and university buildings, housing and offices'.[1] Figure 3.68 shows the open extruded aluminium mullion section used as the structure of the curtain walling of a school in Bagnol-sur-Chèze in 1958. Jean Prouvé designed the curtain walling assembly for the architects of this school, Badani & Roux-Dorlut.

This late 1950s engagement by Jean Prouvé in the design of systems using aluminium extrusions is included here to illustrate the development of technology and technique and not as a full case study.

Note

1 C. Coley (2006), *CIMT*, in A. von Vegesack, C. Dumont D'Ayot and B. Reichlin (eds), *Jean Prouvé: The Poetics of the Technical Object*, Vitra Design Museum, Stiftung GmbH, Weil am Rhein, p. 160.

Fig 3.67 Drawing of an extruded aluminium glazing mullion by Jean Prouvé

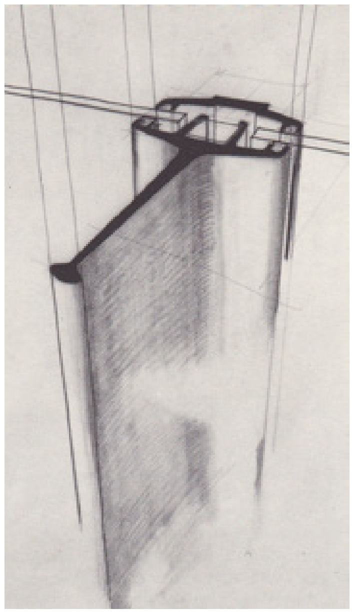
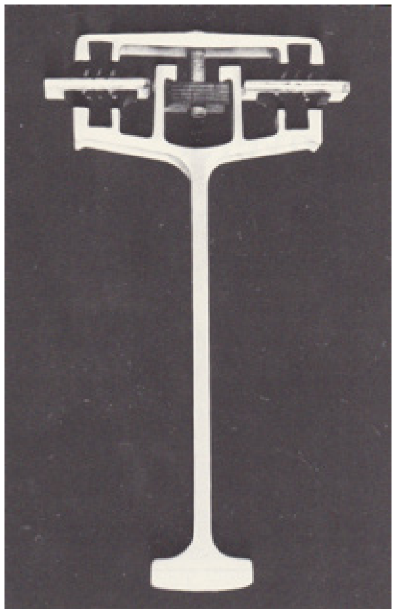


Fig 3.68 Extruded aluminium mullion by Jean Prouvé



World Headquarters of the Pepsi-Cola Company, New York, USA: Architect Skidmore, Owings & Merrill, 1959

The 11-storey World Headquarters of the Pepsi-Cola Company is located on a corner block at 500 Park Avenue, New York. This is a crisply detailed Manhattan office. Skidmore, Owings & Merrill used a recessed service tower, clad in black granite, to separate this office from its neighbour. The street, façade has an articulated aluminium curtain walling, which creates an elegant and transparent yet modest office tower. The spandrel panels are

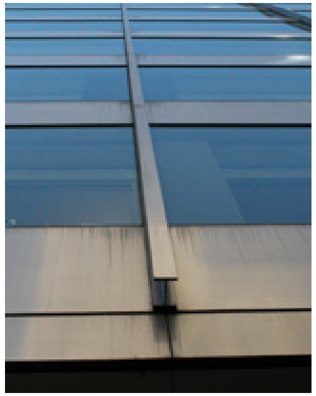
Fig 3.69 Night view of the World Headquarters of the Pepsi-Cola Company, New York

Fig 3.70 By day the vertical blinds create a muted transparency

6.35mm (0.25″) thick anodised aluminium and the external I-beams are polished aluminium extrusions. The grey-green glass panes are single sheets of 13mm (0.5″) polished plate glass measuring 2,743mm (9′) high by 3,962mm (13′) wide. The curtain walling is an assembly of open extruded aluminium sections with the primary architectural expression being generated by the external aluminium I-beam mullions. Gordon Bunshaft was the design partner working with project architect Natalie de Blois and her team within Skidmore, Owings & Merrill. The World Headquarters is described in the Landmarks Preservation Commission listing as an 'understated monument to corporate America'.[1] This building is currently occupied by ABN-Amro Bank.

Note

1 Landmarks Preservation Commission, (20 June 1995), Designation List 265 LP-1920, www.nyc.gov/html/lpc/downloads/pdf/reports/pepsibldg.pdf (accessed September 2013).



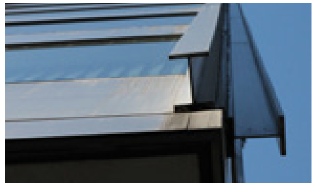


Fig 3.71–Fig 3.72 [above] External details of the articulated aluminium curtain walling, photographed in December 2013

Fig 3.73 500 Park Avenue, photographed December 2013 across this busy Manhattan street

Crown Zellerbach Corporation Headquarters, San Francisco, California, USA: Architect Skidmore, Owings & Merrill, 1959

Located on a triangular site in downtown San Francisco, this 20-storey office designed by Skidmore, Owings & Merrill was constructed between 1957 and 1959. The design is based on a 1,676mm (5′6″) module to generate good in-use flexibility. The aluminium curtain walling has many of the characteristics of curtain-walling systems that would be developed by the 1980s. The external box section mullions are still made of open extrusions; however, the glass is supported and sealed by neoprene gaskets, not caulking. The external box mullions incorporate grooves to facilitate the washing of this glass and aluminium curtain walling.

Fig 3.74 Crown Zellerbach Corporation Headquarters, San Francisco, California

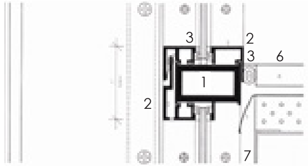


Fig 3.75 [above] Crown Zellerbach Corporation Headquarters: vertical section through the curtain wall at floor level

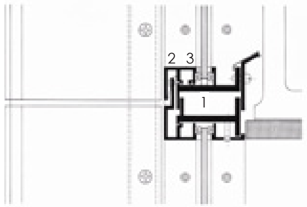


Fig 3.76 [above] Horizontal section through a mullion of the curtain wall

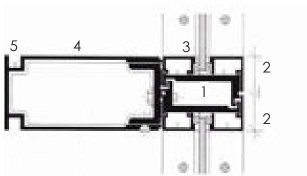


Fig 3.77 [above] Vertical section through the curtain wall at ceiling level

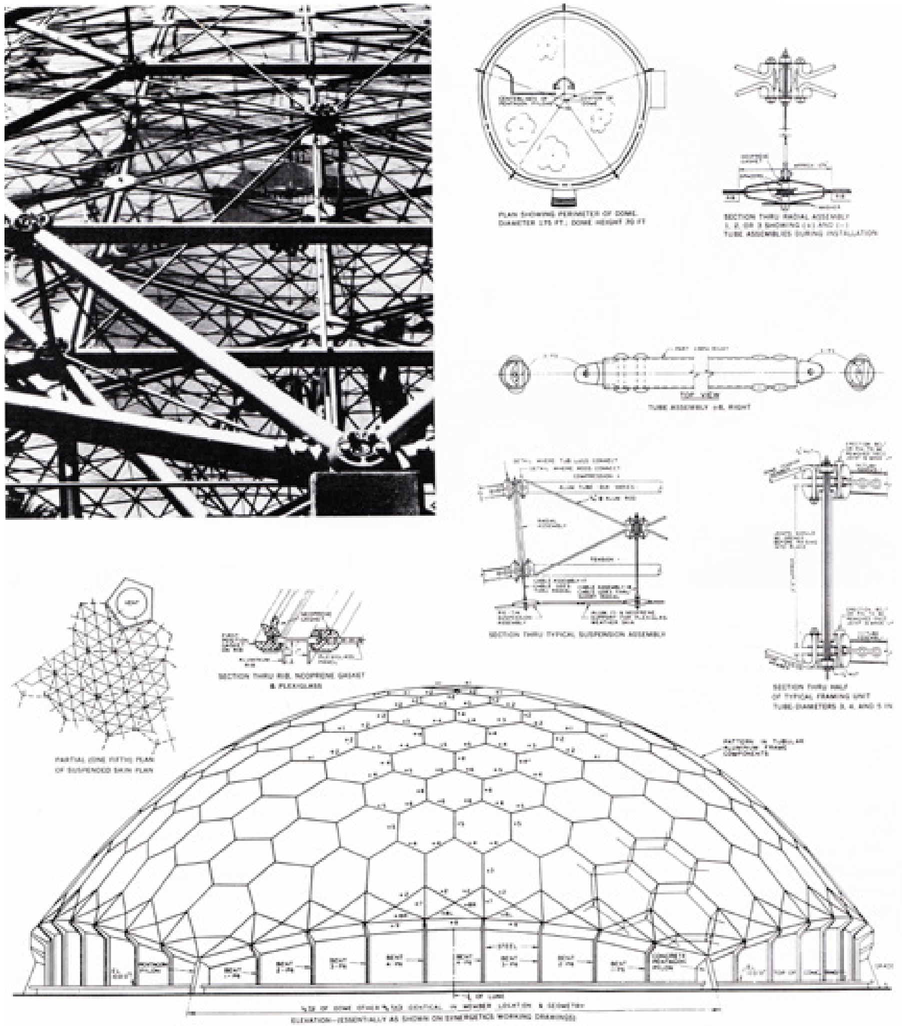
1 aluminium framing
2 aluminium glazing strips
3 neoprene gasket
4 aluminium mullion
5 grooves for window-washing scaffold
6 stone cill
7 flashing
8 suspended plaster ceiling

Fig 3.78 [right] Façade detail

Climatron, St Louis, Missouri, USA: Engineer Richard Buckminster Fuller, 1960

The Climatron is a 53m-diameter geodesic dome designed by Richard Buckminster Fuller with architects Murphy and Mackey and completed in 1960. This dome, in St Louis, Missouri, houses a conservatory with a range of climatic conditions ranging from tropical rainforests to dry tropical and oceanic climates. The external structure of aluminium tubes and aluminium rods is sealed by an acrylic skin, which is held in place by neoprene gaskets. Between 1988 and 1990, the Climatron was refurbished, including the replacement of the acrylic skin with 2,425 panes of heat-strengthened laminated glass with an inner low-emissivity coating, which helps to retain solar energy thus reducing heating costs.

Fig 3.79 Detail and drawings of Climatron, St Louis, Missouri



First City National Bank, Houston, Texas, USA: Architect Skidmore, Owings & Merrill, 1961

Skidmore, Owings & Merrill designed a group of buildings for the First City National Bank, in Houston, Texas: a banking hall, a parking garage and a 32-storey office tower. The steel frame of this tower is fireproofed with concrete and clad in Vermont marble. The curtain walling is recessed by 1,524mm (5′) to provide solar protection and comprises visible neoprene gaskets on open aluminium sections.

Fig 3.80 First City National Bank and surrounding buildings, Houston, Texas

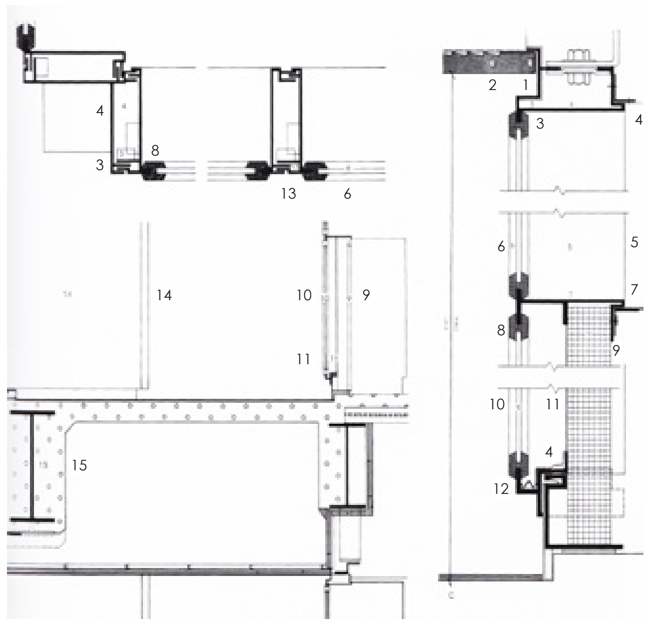


Fig 3.81 Curtain walling details

A horizontal section through corner of building at window level.
B section through ceiling and spandrel.
C vertical section through exterior wall.

1 metal plaster stop
2 cement plaster soffit
3 aluminium splice at expansion
4 extruded aluminium framing
5 aluminium mullion
6 polished grey plate glass
7 extruded aluminium cill
8 neoprene gasket
9 rigid insulation
10 tampered grey plate glass, unpolished inside, polished outside
11 fabric flashing
12 weep hole baffel
13 sealant
14 marble faced column
15 longitudinal girder

Chase Manhattan Bank, New York, USA: Architect Skidmore, Owings & Merrill, 1961

The evocative photograph below, Figure 3.82, depicts the 60-storey Chase Manhattan Bank in New York. This skyscraper was designed by Skidmore, Owings & Merrill and completed in 1961. It illustrates the changing eras of Manhattan. Skidmore, Owings & Merrill had spent the previous decade developing aluminium curtain walling in close collaboration with industry and the development of full curtain-walling systems was still over ten years in the future. The curtain walling of the Chase Manhattan Bank has external I-beam aluminium mullions and aluminium cladding to columns and spandrel panels.

Fig 3.82 Chase Manhattan Bank contrasts sharply with its neighbours in 1961

Hartford Fire Insurance Company Offices, Chicago, Illinois, USA: Architect Skidmore, Owings & Merrill, 1961

The third office building designed by Skidmore, Owings & Merrill on Monroe Street in Chicago is 20 storeys high and is characterised by grey anodised aluminium cladding, grey glass and grey anodised aluminium framing to the window wall. However, the external concrete frame of columns and beams is clad with a skin of Minnesota granite.

Fig 3.83 Hartford Fire Insurance Company Offices, Chicago

TWA Terminal, New York International Airport, USA: Architect Eero Saarinen, 1962

Famous for its freeform concrete shell structure that is intended to evoke flight, the Trans World Airlines [TWA] Terminal at New York International Airport [now JFK] was designed by Eero Saarinen and completed in 1962. The outward-sloping glass walls of the terminal are formed from gasketed curtain walling on an extruded aluminium carrier that is supported by steel trusses. Antonio Román observes:

> In the TWA Terminal, Saarinen took the passenger's impression and experience to the limit. The idea was that wherever he [or she] went in the terminal, the passenger would be able to sense the excitement of travel.[1]

The TWA Terminal was landmark listed in 1994; however, this only protects its exterior.

Note

1 A. Román (2002), *Eero Saarinen: An Architecture of Multiplicity*, Laurence King, London, p. 67.

Fig 3.84 TWA Terminal, New York International Airport

Metalka Building, Ljubljana, Slovenia: Architect Edo Mihevc, Façade Design Branko Kraševac, 1963

Fig 3.85 Aluminium façade of Metalka Building, Ljubljana

The Metalka Building in Ljubljana was designed by architect Edo Mihevc and completed in 1963. It was the first high-rise office building in the city. Metalka is an import/export firm dealing with metal products, including aluminium sheets, castings and extrusions produced by IMPOL. Boeing is one of its customers. Metalka's intention was that the office building should express its business and showcase the use of modern materials, especially aluminium. Mihevc used the Seagram Building in New York, designed by Ludwig Mies van der Rohe, as an inspiration for the new building in the town centre of Ljubljana, especially its urban massing of a high-rise tower set back from the street and fronted by a public square.

The façade, however, is more like that of the Alcoa Building in Pittsburgh, designed by Harrison & Abramovitz; see pp. 61–63. The façade was designed and developed by Branko Kraševac in 1960 and 1961. It is assembled from aluminium curtain walling with pressed aluminium sheets, where the form provides rigidity. The aluminium panels are silver anodised with a little golden reflectivity.

National Olympic Gymnasium, Tokyo, Japan: Architect Kenzo Tange, 1964

The National Olympic Gymnasium, designed by Kenzo Tange, was built for the 1964 Tokyo Olympics. On completion, it was considered to have the largest suspended roof in the world. The ceiling comprises an internal aluminium sheet with glass wool acoustic insulation above, supported by steel beams at 4m intervals. The main external cables are wrapped in concrete and clad in aluminium jackets, and the roof is covered in 4.5mm thick aluminium plates.

Fig 3.86 Suspended aluminium roof of the National Olympic Gymnasium, Tokyo

Grossman House, Studio City, California, USA: Architect Raphael Soriano, 1965

The Grossman House, designed by Raphael Soriano, was built in Studio City in 1965 and billed as the world's first all-aluminum home. However, despite the architect's assertions, it was not the first aluminium house. Albert Grossman, an aluminium sub-contractor and cousin of the inventor of Glide aluminium sliding windows, commissioned the Californian architect Soriano to design him an aluminium house using his own company's products. Soriano recognised the potential of using aluminium in housing and developed what he called the 'all-aluminum' building system later introduced as 'Soria Structures'.[1] He used the Grossman House as an opportunity to build a showcase house in Los Angeles. However, two-thirds of the way through construction, Soriano walked off the job, leaving Grossman to supervise its completion.

The 975m² (3,200ft²) one-storey house is contained under a flat roof punctured at two points to allow light into the entrance court and an inner courtyard. The structure consists of 11 sets of square-section aluminium columns sandwiched between pairs of back-to-back C-section aluminium beams in a 3m × 6m (10′ × 20′) grid pattern.[2] The aluminium is anodised in jewel-like hues of purple, bronze and blue. Twenty-eight aluminium sliding-glass doors enclose the house, which the Grossmans claim are still maintenance-free.[3]

Notes

1 W. de Wit and C. J. Alexander (2013), *Overdrive: LA Constructs the Future, 1940–1990*, Getty Research Institute, Los Angeles. p. 152.
2 N. Jackson (1996), *The Modern Steel House*. Dah Hua Press, Hong Kong, p. 115.
3 K. Salant (2000), *A 1963 home framed and clad in aluminum is still virtually maintenance-free today*, Los Angeles Times, 2 April.

Fig 3.87 Grossman House, Studio City, California

Alcoa Building, San Francisco, California, USA: Architect Skidmore, Owings & Merrill, 1967

Alcoa's 24-storey office tower in San Francisco is built above a public garage. This is facilitated by an exoskeleton steel structure that is clad in bronze anodised aluminium. This structure was designed to sustain seismic loads during earthquakes. The external structure is set off the aluminium curtain walling by nearly 500mm (18″).

Fig 3.88 The Alcoa Building in San Francisco was constructed as a stiff cage, designed to withstand seismic forces

Nuremberg Congress Hall, Nuremberg, Germany: Architects Ludwig & Franz Ruff, 1938 and 1968

Local architects Ludwig and Franz Ruff designed the Nuremberg Congress Hall as part of the Nuremberg master plan, which covered 11 square kilometres. This was designed for the Nazi party rallies, of which six took place between 1933 and 1938. Franz Ruff continued the design of the Congress Hall after his father's death in 1934. Construction commenced in 1935, but was not completed. In 1968, the first Kalzip roof in Europe was installed, protecting what was left of the listed building. Kalzip aluminium roofing is assembled from roll-formed aluminium sheet, which has an additional top layer or plating layer, of approximately 5 per cent thick AlZn1 (aluminium zinc alloy). The Congress Hall is the largest Nazi relic left standing and now houses a Documentation Centre in its north wing.

In 1993, the German Federal Institute for Materials Research and Testing [BAM] carried out tests on three Kalzip roofing systems, Nuremberg Congress Hall being one of the selected projects. The Congress Hall is located in a combined urban/rural climate where the main pollutants recorded are carbon dioxide and carbon monoxide, neither of which have any major effects on aluminium. The tests showed that pitting corrosion was restricted to the plating layer and not to the bulk material. Further tests undertaken in 2009, 41 years after installation, revealed that the corrosion had not extended to the base aluminium. The BAM stated in its report: 'The pitting corrosion effects in the plating layer detected in the cross section stop at the bulk material and thus do not affect the function of the roofing after 41 years of use ... long durability can be expected'.[1]

Note

1 Kalzip Ltd (April 2011), *Durability and Corrosion Testing*, available online at www.kalzip.co.uk/PDF/uk/BAM%20Durability%20and%20corrosion%20testing.pdf (accessed November 2013). This English translation retains the German spelling of Nurenberg – Nürnberg.

Fig 3.89 Aerial view of Kalzip's profiled aluminium standing seam roof of the Nuremberg Congress Hall, installed in 1968

Cambridge Maximum Space House, Cambridge, England: Architect John Hix, 1969

The Cambridge Maximum Space House [MSH] was designed and built by students from the University of Cambridge School of Architecture under the direction of John Hix. The aim of the project was to create a prototype low-cost house that explored planning flexibility. The aluminium frame was erected first and then glazing with services being subsequently fixed to greenhouse-like structure. The MSH was used by the School of Architecture for conferences and exhibitions and as studio accommodation for research students.[1] It then formed a temporary home for the Martin Centre. The MSH lasted almost 15 years before disassembly.

Note

1 J. Hix (1974), *The Glass House*, The MIT Press, Cambridge, MA, p. 171.

Fig 3.90 Cambridge Maximum Space House

UNESCO Building 5, Paris, France: Architect Bernard Zephus, Façade Design Jean Prouvé, 1969

Working with lead architect Bernard Zephus on the façades of UNESCO Building 5, Jean Prouvé demonstrated his experience in developing light metal cladding. Brise soleil are formed from simple curved, anodised aluminium sheets, fixed to the outer glazing frame and incorporating opaque ventilators, which provide ventilation and eliminate the need for opening windows – a tectonic tactic that was often used by both Louis I. Kahn and Le Corbusier. The anodised aluminium window frames incorporate nylon thermal breaks. Improving the thermal resistance of aluminium window frames did not become the norm in Europe until the 1980s. Cast aluminium gratings provide cleaning access.

Fig 3.91 Curved, anodised aluminium sheets of the façade of UNESCO Building 5, Paris form integrated solar shading

Packing Hall, Schumacherwerder Overseas Centre, Hamburg, Germany: 1970

The aluminium Kalzip roof of the Packing Hall of the Schumacherwerder Overseas Centre, in the Freeport of Hamburg, was installed in 1970. The hall is situated in the harbour area of the city, a marine environment where sodium chloride is the major atmospheric corrosive. This was one of three buildings tested by the German Federal Institute for Materials Research and Testing [BAM] to evaluate the durability and corrosion of aluminium. The tests showed that the difference between the inner and outer surfaces after nearly 40 years of exposure was 7μm (inner 47μm, outer 40μm). BAM stated in its report: 'After 40 years exposure, the bulk material is not yet affected. At the present moment the function of the roof is completely in a good condition.'[1]

Note

1 Kalzip Ltd (April 2011), *Durability and Corrosion Testing*, available online at www.kalzip.co.uk/PDF/uk/BAM%20Durability%20and%20corrosion%20testing.pdf (accessed September 2013).

Fig 3.92 Kalzip aluminium roof of the Packing Hall of the Schumacherwerder Overseas Centre, Hamburg

Storage Facility, Essen, Germany: 1974

This storage facility, operated by a metal business, was erected in 1974 in an industrial area of Essen, where the most frequently encountered pollutants are sulphur dioxide and hydrogen chloride. This was the third Kalzip project tested by the German Federal Institute for Materials Research and Testing [BAM]. At this location, the first sample was taken from the eaves; whilst 'some pitting to the plating layer is apparent on both sides, the core material remains unaffected'.[1] The second sample showed 'pitting to the outside but only very limited damage to the inside, neither affecting the bulk material'.[2] The difference after 36 years was 12μm, a finding that led the BAM to state: 'The investigations reveal numerous corrosion effects which, however, do not extend to the bulk material'.[3]

Notes

1 Kalzip Ltd (April 2011), *Durability and Corrosion Testing*, available online at www.kalzip.co.uk/PDF/uk/BAM%20Durability%20and%20corrosion%20testing.pdf (accessed September 2015).
2 Ibid.
3 Ibid.

Fig 3.93 Kalzip aluminium roof of the Storage Facility, Essen

Television Centre, Ljubljana, Slovenia: Architect France Rihtar, Façade Design Branko Kraševac, 1974

Branko Kraševac, in collaboration with architect France Rihtar, designed the façade for the Television Centre in Ljubljana between 1967 and 1974. Kraševac was involved in almost all important aluminum façades in Slovenia, the northern part of the former Yugoslavia. Here, at the Television Centre, he used cast aluminum panels, which were cast horizontally so that the surface was marked with the form of cooling material. This gives a visual effect that is comparable to stone. This is the third example of cast aluminium panels in this review of almost 100 years of the use of aluminium in architecture and the built environment.

Fig 3.94 Cast aluminium cladding panels creating a stone effect on the façade of the Television Centre, Ljubljana, photographed 2013

Fig 3.95 Façade of the Television Centre, Ljubljana, photographed 2013

Fig 3.96 Detail of cast aluminium cladding panels, photographed 2013

Fig 3.97 Faceted street elevation of the Television Centre, Ljubljana, photographed 2013

Bagsværd Church, Copenhagen, Denmark: Architect Jørn Utzon, 1976

Bagsværd Church, designed by Jørn Utzon, is a Lutheran church on the northern outskirts of Copenhagen. The church has a naturally illuminated interior, with extensive roof lights, allowing light to reflect onto the vaulted concrete ceiling and into the cloister-like circulation spaces. Bagsværd Church combines simple industrial components with a parametrically generated geometry of the sprayed concrete ceiling.[1]

Externally, this church has an agrarian industrial aesthetic. The roof is formed from corrugated aluminium sheathing, fitted by Svend Eckeroth, and is combined with aluminium roof lights by Dansk Velux to enclose the highly crafted interior.[2] Utzon was a highly inspirational bespoke architect. For this church, he used standard systems to create a beautiful but economic architecture. In his drawing below, Figure 3.99, Utzon describes the roof lights: 'Velux – a standard product, impossible to improve'.

Notes

1 M. Stacey (2011), *Concrete: a studio design guide*, RIBA Publishing, London, pp. 177–179.

2 Bagsværd Church, *They Built the Church*, available online at www.bagsvaerdkirke.dk/index.php?id=108 (accessed September 2013).

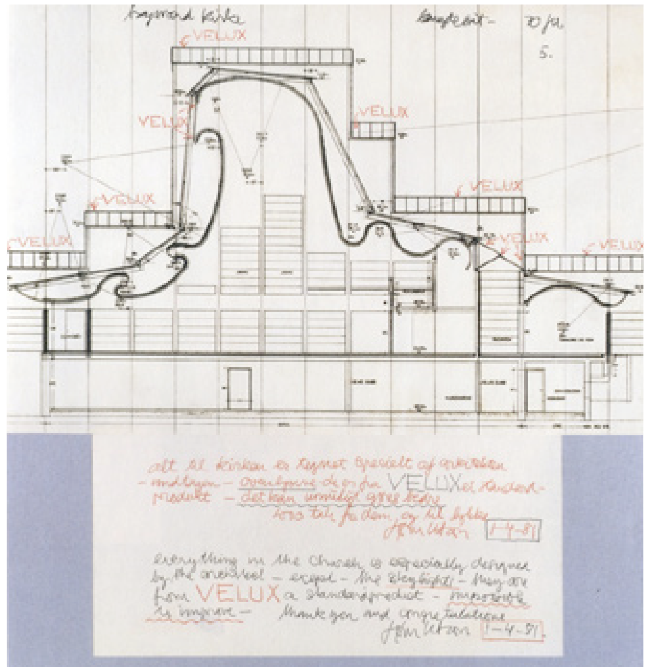


Fig 3.98 Jørn Utzon's sectional drawing of Bagsværd Church

Fig 3.99 Bagsværd Church is an apparently simple assembly, primarily made of standard products

Fig 3.100 Velux roof lights flood daylight into the cloister-like circulation within the church

Yale Center for British Art, New Haven, Connecticut, USA: Architect Louis I. Kahn, 1977

The internationally acclaimed American architect Louis I. Kahn designed the Yale Center for British Art, which was completed in 1977, after his death in 1974. The Center is composed around two inner courtyards, which allow natural light to penetrate the building's deep plan with a coffered skylight system of acrylic and aluminium. After the mixed success of his use of natural light at the Kimbell Art Gallery (1966–72) and how it was moderated by reflectors and the materials used for the roof lights, Kahn again consulted with the lighting designer Richard Kelly at an early stage in the design development of the Yale Center for British Art. This resulted in large openings with carefully positioned louvres. The openings in the concrete frame are covered in a series of acrylic skylight domes, supported on an aluminium frame. On top of the domes, outside the building, are a series of aluminium louvres, which prevent any direct sunlight damaging the paintings.[1]

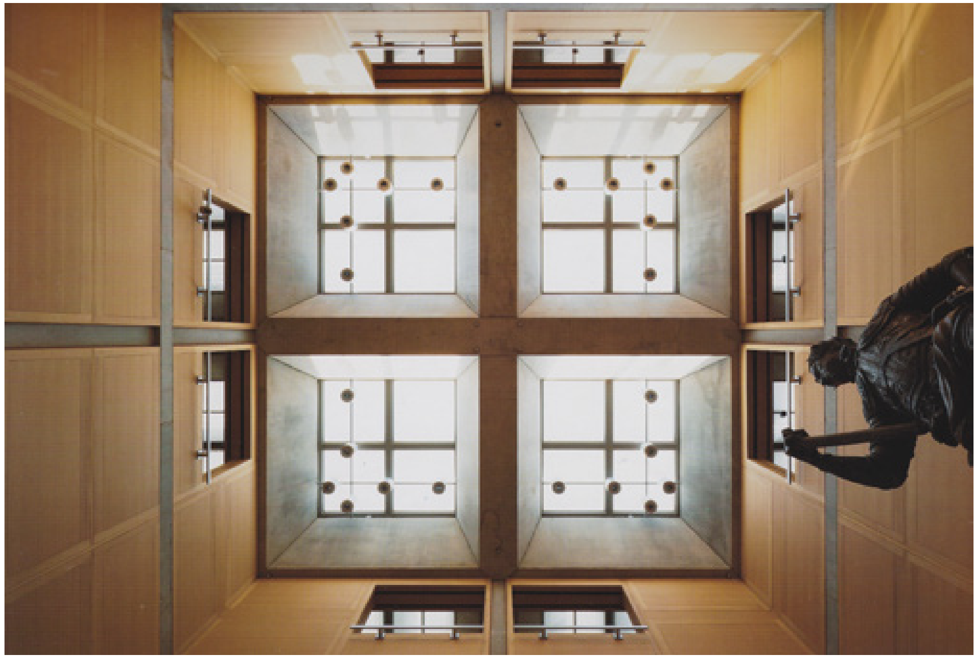
The original steel curtain wall of the Center suffered thermal and moisture problems, resulting in some fogged areas of glazing. In 2006, this was replaced with an aluminium curtain wall, capable of responding to temperature changes and bringing the gallery up to contemporary building standards.

Fig 3.101 Yale Center for British Art

Fig 3.102 Atrium of the Yale Center for British Art

Note

1 E. R. Ford (1996), *The Details of Modern Architecture, Volume 2: 1928 to 1988*, The MIT Press, Cambridge, MA, pp. 333–335.



Sainsbury Centre for Visual Arts, Norwich, England: Architect Foster Associates, 1978

The Sainsbury Centre for Visual Arts at the University of East Anglia (UEA), designed by Norman Foster and colleagues (Foster Associates, now Foster + Partners), was originally clad in an integrated system of aluminium panels, aluminium louvres and panels that were fully glazed, yet had the same aluminium edge detailing. The ribbed panels were formed using superplastic aluminium and finished with silver anodising. These panels had to be replaced due to premature failure of the superplastic aluminium cladding. The cause of this failure has never been formally reported. However, it is understood to have been the combination of two factors: excessive thinning at the hemispherical corners and the production of sulphuric acid, caused by water coming into contact with the phenolic core, leading to corrosion of the aluminium. Too often, building 'failures' are buried in insurance settlements. It should be noted that the Sainsbury Centre, which was completed in 1978, was a very innovative application of superplastic aluminium.

The ladder gasket and supporting aluminium framing was reused when, in 1998, the Sainsbury Centre was reclad with flat aluminium cladding by Cupples.

Fig 3.103 Sainsbury Centre for Visual Arts original panel detail by Foster Associates

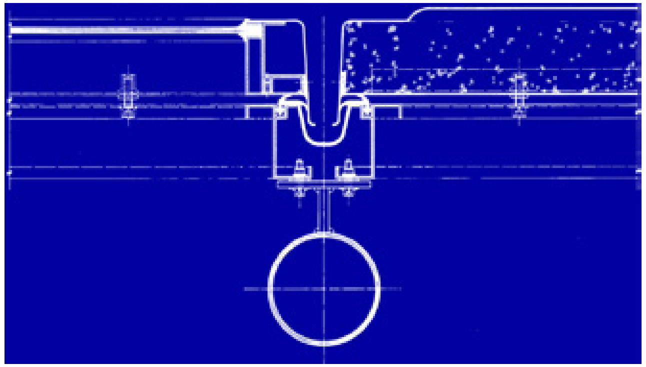


Fig 3.104 Superplastic aluminium cladding and glazing of the Sainsbury Centre for Visual Arts, architect Foster Associates

Hongkong and Shanghai Bank Headquarters, Hong Kong: Architect Foster Associates, 1986

Conceived during a sensitive period in the former colony's history, the brief for the Hongkong and Shanghai Bank Headquarters was a statement of confidence: to create 'the best bank building in the world'.[1] Foster Associates (now Foster + Partners) won the design commission for the building in a competition in 1979, practical completion was achieved in May 1985 and it was officially opened in 1986. This new headquarters virtually reinvented the office tower.[2]

The requirement to build in excess of one million square feet of office accommodation in a short timescale suggested a high degree of prefabrication, including factory-finished modules. The need to build downwards and upwards simultaneously led to the adoption of a suspension structure, with pairs of steel masts arranged in three bays. As a result, the building form was articulated in a stepped profile of three individual towers, respectively 29, 36 and 44 storeys high, which created floors of varying width and depth and allowed for garden/refuge terraces. The mast structure allowed another radical move: pushing the service cores to the perimeter to create deep-plan floors around a ten-storey atrium.

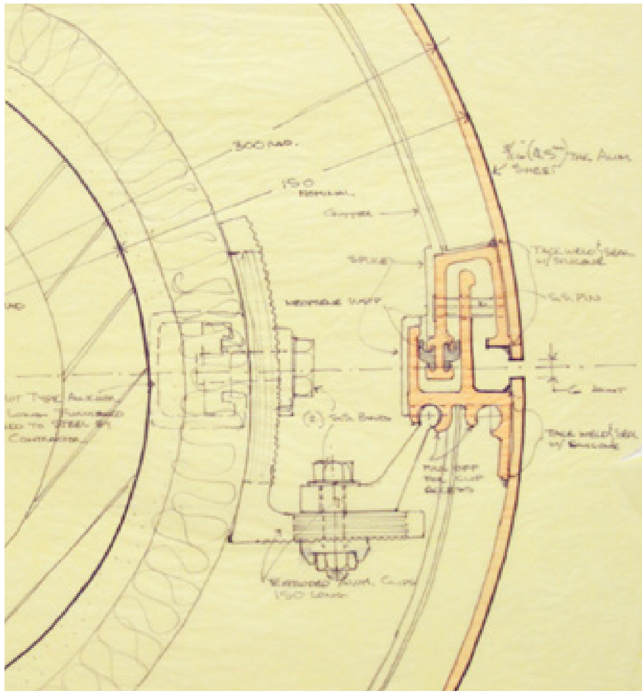


Fig 3.105 [left] Foster Associates' rainscreen cladding detail drawing of the primary structure of the Hongkong and Shanghai Bank Headquarters

Fig 3.106 [right] Hongkong and Shanghai Bank Headquarters

The hanging structure of the bank, liberating unrestricted floor plates, was designed with Arup and has antecedents in the work of engineers Owen Williams and Richard Buckminster Fuller. The bespoke quality of the curtain walling harks back to the development of aluminium curtain walling in New York during the 1950s, as every detail reveals the close collaboration between the architect and the façade supplier. Chris Abel suggests that Norman Foster's work bridges the First and Second Machine Ages and that the Bank Headquarters should be considered 'the first major building of the Second Machine Age'.[3] The design of the bank has great conceptual clarity; however, the geometric complexity of the aluminium rainscreen cladding provided a

Fig 3.107 Die cast aluminium brie soleil, curtain walling and cladding of the Hongkong and Shanghai Bank Headquarters

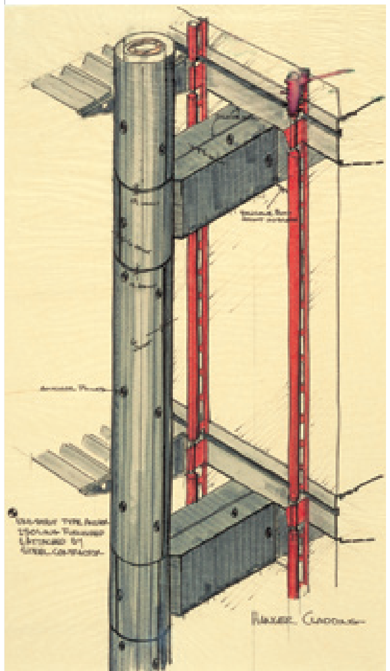


Fig 3.108 Foster Associates' three-dimensional sketch investigating the relationship between the rainscreen cladding and the louvred brie soleil

significant challenge, beyond any previous high-rise architecture. Over a three-year period, Foster Associates worked closely in its London office with American curtain-walling specialist Cupples to develop this bespoke assembly. Colin Davies observes that 'more than 2,500 sketches were prepared by the Foster Associates design team and these called forth no less than 10,000 shop drawings from Cupples'.[4] This was followed by the prototyping and testing of all major assemblies and junctions.

The rainscreen cladding is 5mm thick aluminium stiffened with aluminium extrusions and detailed to provide a consistent 9mm shadow gap between panels. The agreed tolerance on panels is ±0.5mm; this was achieved by the pioneering use of digital fabrication technologies. Now over 25 years old, the carefully detailed aluminium curtain-walling system, which includes die-cast aluminium brise soleil and aluminium rainscreen cladding, all finished in PVDF, looks as crisp as the day the building opened.

Notes

1 M. Stacey, *Hongkong and Shanghai Bank, HQ*, The Future Builds with Aluminium, available online at http://greenbuilding.world-aluminium.org/nc/benefits/durable/hongkong-and-shanghai-bank-hq.html?sword_list[]=bank (accessed September 2015).

2 M. Stacey (2010), *Aluminium, Architecture and Human Ecology*, in L. Katgerman and F. Soetens (eds), *New Frontiers in Light Metals: Proceedings of the 11th International Aluminium Conference*, IOS Press, Amsterdam, pp. 3–12.

3 C. Abel (1989), *From hard to soft machines*, in I. Lambot (ed.), *Norman Foster: Building and Projects of Foster Associates, Volume 3: 1978–1985*, Hong Kong, Watermark, p. 17.

4 C. Davies (1989), *Hongkong Bank Cladding*, in I. Lambot (ed.), *Norman Foster: Building and Projects of Foster Associates, Volume 3: 1978–1985*, Hong Kong, Watermark, p. 222.

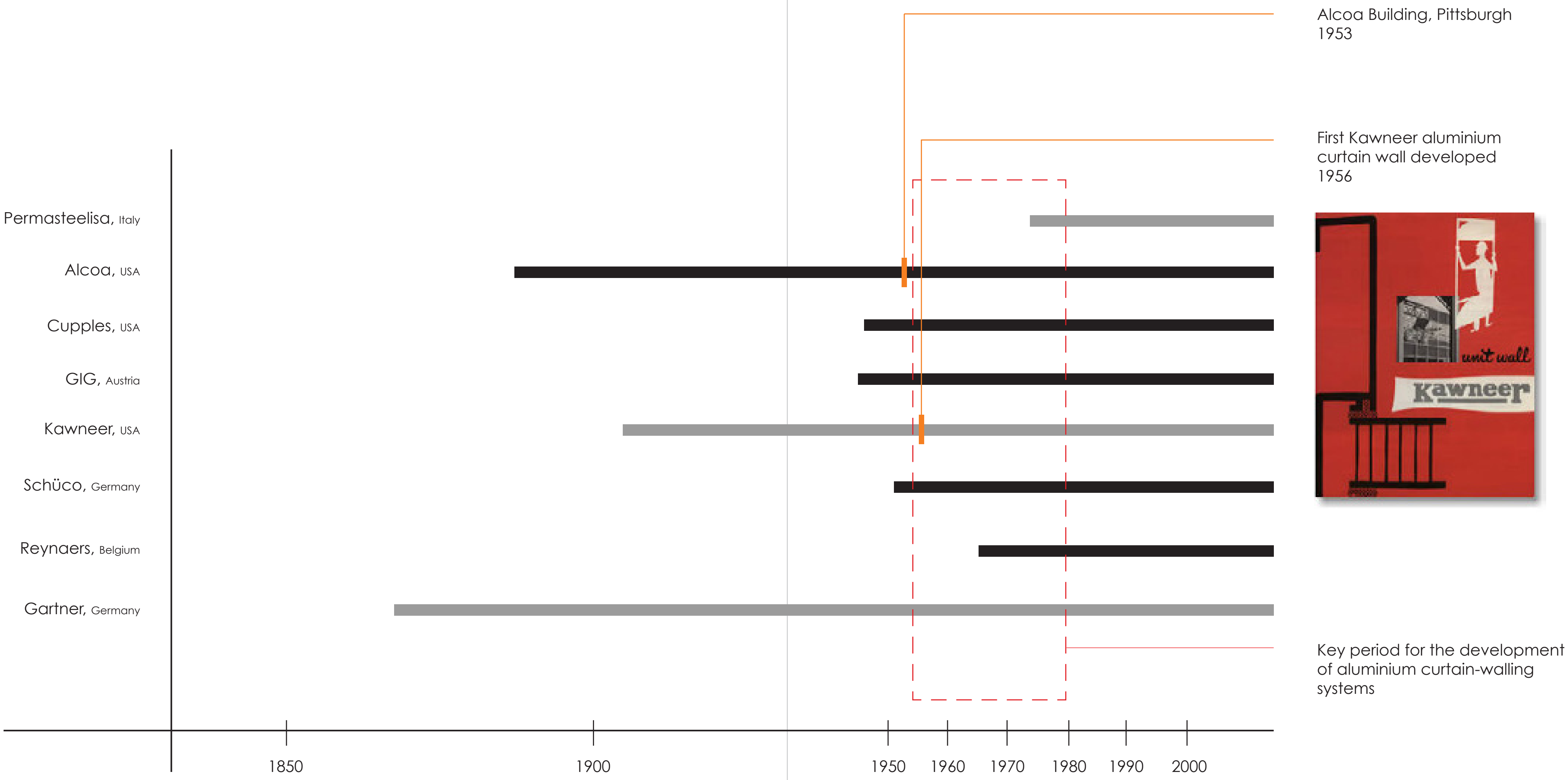


Fig 3.109 Graph of the development of aluminium curtain-walling systems

Development of Curtain Walling from Bespoke to Tested Systems

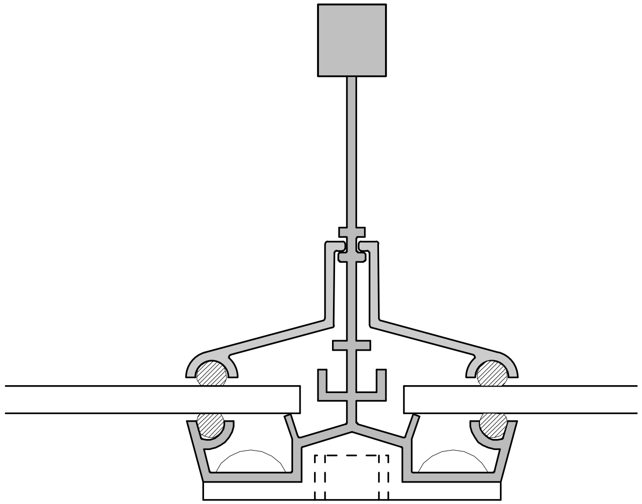


Fig 3.110 Typical extruded aluminium patent glazing section

The key period for the development of curtain walling was the 1950s in the USA, with many projects in Manhattan, New York. However, the pioneering work was undertaken in the UK and France before and after the Second World War, with Jean Prouvé as a key pioneer, the world's leading exponent of light metal cladding, as set out earlier in this chapter.

All of the early American curtain-walling projects were bespoke assemblies, typically formed from open aluminium extruded sections combined with press-braked sections. Extruded box sections, although known in the 1960s, did not become standard for curtain walling until the 1980s. One of the first reports to feature pressure-equalised curtain walling, the basis of contemporary reliable curtain walling, was the Architectural Aluminum Manufacturers Association of America report dated 1971.[1] In the UK during the 1960s and 1970s, open extruded patent glazing with asbestos codes as gaskets was a very typical specification – for example, James Stirling and James Gowan's seminal Leicester Engineering Building, completed in 1963, or the extension of Liverpool Playhouse, designed by architects Hall, O'Donahue & Wilson.

Although gasketed systems have their origins in the USA, with the General Motors Technical Center by Eero Saarinen being the first major use of a neoprene gasketed curtain-walling system, the key developments were in the UK. In the early 1970s, Modern Art Glass

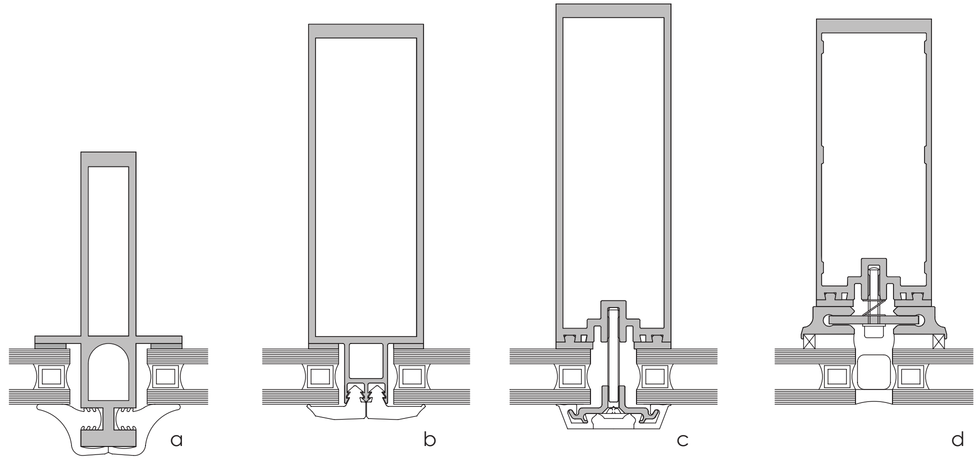


Fig 3.111 **a** Presslock, **b** Don Reynolds, **c** Stoakes Systems gasket cladding and curtain walling systems with **d** Stoakes Systems silicone-bonded curtain walling

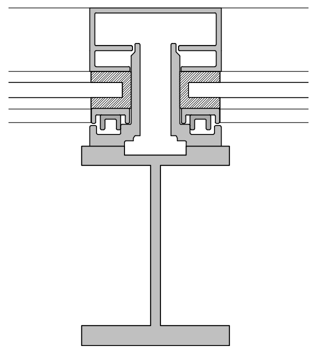


Fig 3.112 Bespoke aluminium curtain-walling mullion of the World Headquarters of the Pepsi-Cola Company, designed by Skidmore, Owings & Merrill, 1959

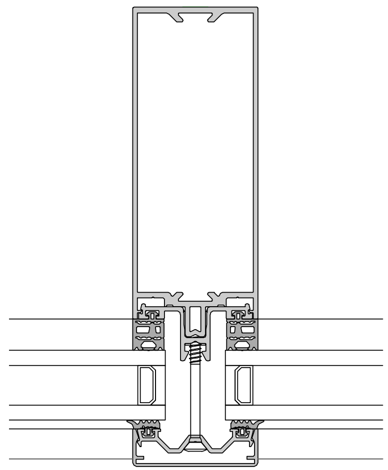


Fig 3.113 Contemporary pressure-equalised curtain-walling section (double-glazed)

Ltd., in consortium with Leyland and Birmingham Rubber Co. and Aluminium Systems of Dublin, developed the Pressure Glaze and the Presslock systems using structural neoprene sections. Farrell and Grimshaw specified these for the Herman Miller Factory in Bath (1976) and Winwick Quay in Warrington (1978).[2] In 1983, Don Reynolds Ltd. was granted a patent for a curtain-walling system using a face-applied gasket. By the late 1980s, a Department of Trade and Industry [DTI] report noted that Don Reynolds had become one of the leading exporters of curtain walling from the UK, based essentially on a single design idea, i.e. a structural silicone gasket, in a market otherwise dominated by European curtain-walling companies.[3] The structural silicone gaskets for this system were developed by Don Reynolds, primarily with Dow Corning, and extruded by Silicone Altimex. By using silicone extrusions, Don Reynolds was able to offer a range of gaskets with guaranteed weatherability and physical stability between −60°C and +200°C, in a range of colours.[4]

Although the computer numerical control [CNC] of machinery, such as press brakes for metal forming, had been introduced in the USA in the 1950s,[5] and noting earlier computer-aided design [CAD] software, a key date for the design of mechanical and architectural components was 1982, when AutoCAD was released and swiftly gained wide adoption by industry, engineers and architects. In 1986, Leslie Parks wrote: 'Extensive use is made of the CAD/CAM approach to section design to save weight without penalising strength in extruded [aluminium] sections. Average percentage weight reductions achieved 1982–1985 by industry are: building sections 10.2, window sections 26.4, carpet edging 22.7 and greenhouses 33.9.'[6]

Two other key developments were allied and complementary to the use of CAD in driving weight reductions in the use of aluminium whilst maintaining or even improving performance. The first was the development of finite element analysis [FEA], which enabled detailed numerical analysis of structures and was first developed by Richard Courant in 1943.[7] The key paper is considered to be *Stiffness and Deflection Analysis of Complex Structures* by Turner, Clough, Martin and Topp, published in 1956.[8] By the 1970s, FEA of structures was common within the aeronautics, automotive and defence industries using mainframe computers. As the cost of computing reduced by the 1980s, this became common practice within the engineering of major architecture projects and products such as aluminium curtain walling.

The second key factor was the development of agreed national test methods, such as BS5368 Parts 1 to 3 (1975–1980), in the UK, which have been replaced by BS EN 1026, 1027 and 12211 (2000), and the American Architectural Manufacturers Association standard for dynamic testing of façades, AAMA 501.1-94, in the USA (now AAMA 501.1-05). These test methods enabled the consistent and comparative holistic testing of windows and curtain-walling assemblies. Such test methods establish the ability of an assembly to sustain wind loading, its air leakage rate, and its resistance to rain penetration in a set of repeated cycles.[9] In essence, the curtain-walling industry was one of the leaders of testing in construction, which is today considered important for other constructional typologies – for example, the on-site testing of air infiltration in low-energy houses.

During the 1980s, a very rapid development in the technology of curtain walling was experienced primarily in the UK and Europe, from bespoke systems by Renzo Piano using cast aluminium wind stiffeners to the development of well-tested curtain-walling systems by major European companies such as Schüco. By the late 1980s, it was possible to specify:

- patent glazing;
- pressure-equalised curtain-walling systems;
- gasket based curtain-walling systems;
- silicone-bonded glazing;
- suspended glazing;
- fire-rated glazing;
- rainscreen cladding.[10]

The development of the use of aluminium in architecture in terms of finishes is discussed in Chapter Five. Towards Sustainable Cities Report 4 *Aluminium: Flexible and Light* brings the development of curtain walling and windows up to date.[11]

Notes

1 Architectural Aluminum Manufacturers Association of America (1971) *Aluminum Curtain Walls – The Rain Screen Principle and Pressure Equalisation Wall Design*, AAMA, New York.
2 M. Stacey (2001), *Component Design*, Architectural Press, Oxford, pp. 34–46.
3 Ibid cited p.46.
4 Ibid.
5 N. Callicot (2001), *Computer-Aided Manufacture in Architecture*, Architectural Press, Oxford.
6 L. Parks (1986), *Aluminium in the home and office*, in A. Barry (ed.), *Aluminium 1886–1986*, Morgan-Grampian for ALFED, London, p. 42.
7 C. Reid (1976), *Courant in Göttingen and New York : The Story of an Improbable Mathematician*, Springer, New York.
8 M. J. Turner, R. W. Clough, H. C. Martin and L. J. Topp (1956), *Stiffness and Deflection Analysis of Complex Structures*, Journal of Aeronautical Sciences, 23(9), pp. 805–823.
9 M. Stacey (2001), *Component Design*, Architectural Press, Oxford, pp. 169–172.
10 A. Brookes and M. Stacey (1988), *Curtain Walling Product Review*, AJ Focus, October, p. 33.
11 M. Stacey (2016), *Aluminium: Flexible and Light*, Cwningen Press, Llundain.

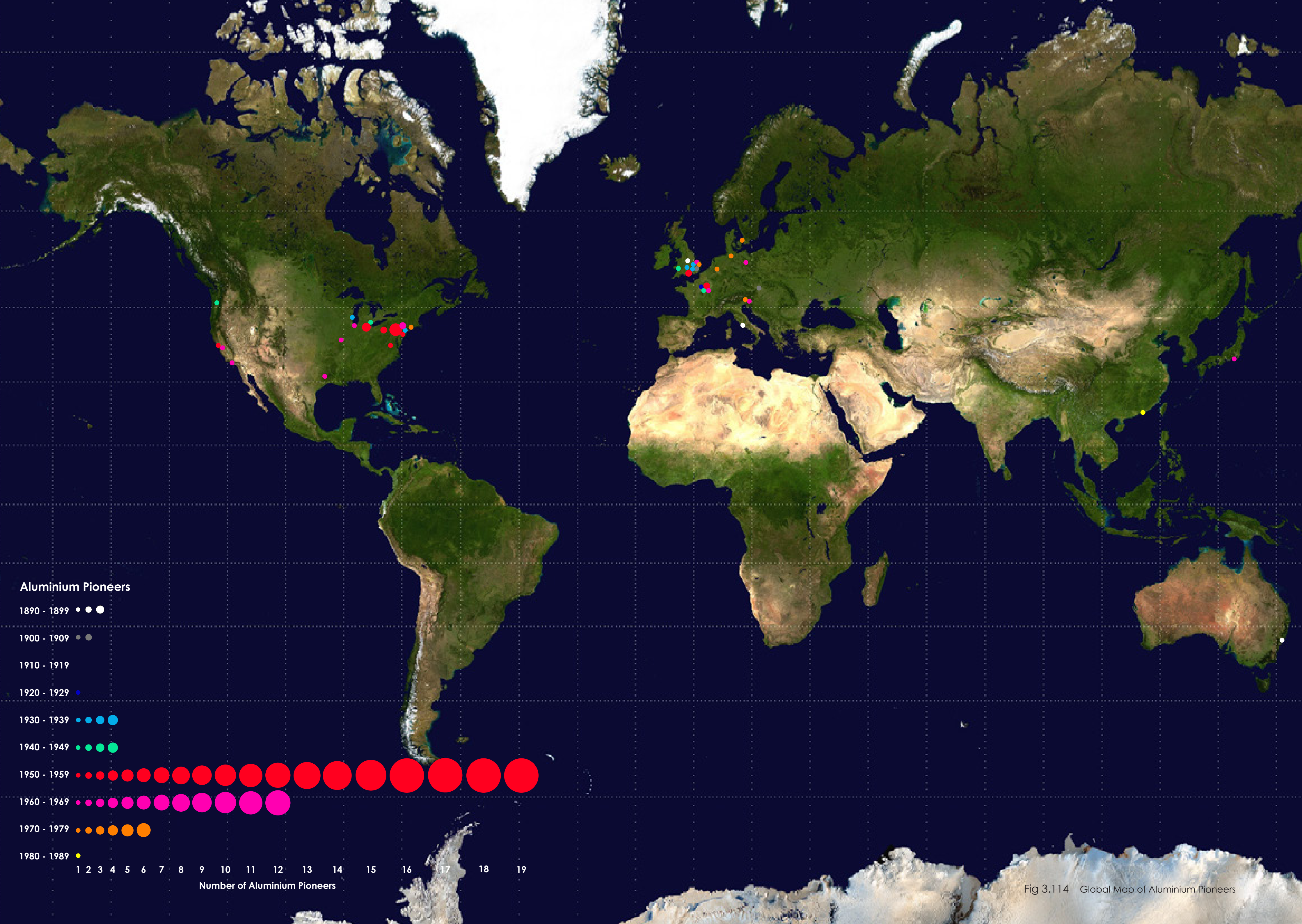


Fig 3.114 Global Map of Aluminium Pioneers

FOUR

four historic exemplars: architecture and aluminium

Four Historic Exemplars: Architecture and Aluminium

Based on the projects identified by the research into aluminium pioneers, see Chapter Three, four great works of architecture that incorporate a significant early use of aluminium were selected for further study and in-depth site visits. The findings of this research and the site visits are set out in this chapter. The projects range in typology from churches to a bank through to an exhibition pavilion.

The four historic exemplars are:

1. San Gioacchino, Rome, Italy,1897, designed by Raffaele Ingami;
2. St Mary the Virgin, Great Warley, Essex, England, 1902, designed by Charles Harrison Townsend with Sir William Reynolds-Stevens;
3. Postsparkasse [Austrian Postal Savings Bank], Vienna, Austria, 1906, designed by Otto Wagner;
4. Aluminium Centenary Pavilion, Paris, France, 1954, designed by Jean Prouvé.

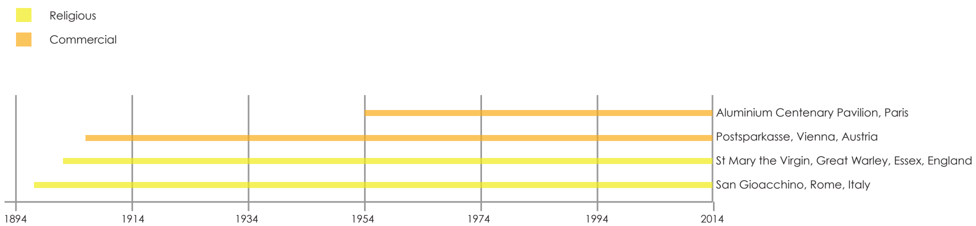


Fig 4.1 Graph showing the age and typology of buildings included in this chapter

San Gioacchino, Rome, Italy:
Architect Raffaele Ingami, 1897

Aluminium mill-finished cladding of the cupola

Fig 4.2 The mill-finish aluminium dome of San Gioacchino, Rome

Date of visit: 2 October 2013

Time of visit: 10am

Visited by: Michael Stacey, Laura Gaskell, Jenny Grewcock and Ben Stanforth

Location: Rome, Italy

Year of completion: 1897

Architect: Raffaele Ingami

Owner/client: Vatican

Weather: Sunny and dry

Access: Unrestricted access

Materials and finish: Aluminium cupola – mill finish

San Gioacchino in Prati Church (San Gioacchino ai Prati di Castello) is dedicated to San Gioacchino (St Joachim), the father of the Virgin Mary, was designed by architect Raffaele Ingami (1836–1908). Construction of San Gioacchino began on 1 October 1891 and the building opened to the public on 20 August 1898. It was consecrated on 6 June 1911 by Cardinal Respighi in honour of Pope Leo XIII.

Fig 4.3 Aluminium panels clad the dome of San Gioacchino, Rome

This is a large church, on the plan of a Latin cross with a central dome. The roofs of the nave, the presbyterium and the transepts are pitched and tiled, but those of the narthex, the wide aisles and ambulatories around the ends of the presbyterium and the transepts are flat. There are half-domes on the ends of the transepts above the ambulatories, with triangular pediments above.

The ribbed octagonal dome, erected in 1897, is an early use of aluminium in architecture; it is the earliest known use for this purpose, and one of the oldest known applications still in service. It is pierced with crystal-like stars, and is crowned by eight angels with their wings spread. There is a lantern on top, with eight arched openings separated by half-columns, and the drum of the dome is pierced by eight quatrefoil windows.

The dome is a lightweight construction with a steel structure, which is clad on the outside in 1.3mm-thick aluminium sheets. The internal skin is also a lightweight panel construction and it is reasonable to suggest that this is also aluminium sheet, like the aluminium ceiling in the Church of St Edmund, King and Martyr, in Fenny Bentley, Derbyshire, that predates San Gioacchino by two years.

Fig 4.4 The blue glow inside the octagonal dome

The aluminium cladding of the dome of San Gioacchino was in excellent condition when visually inspected in September 2013. The cladding of this dome has been regularly inspected and tested during its life. E. W. Skerrey reported in 1982 that 'examination in 1938 and 1953 indicate very little damage to the metal with pitting less than 0.1mm (0.004")' and observed that 'the aluminium sheeting [is] 98.8% pure, whereas the lowest purity in use today is 99.0%'.[1] Raffaele Ingami selected aluminium to clad the dome because it was lightweight, durable and economical in comparison to a lead sheet roof.

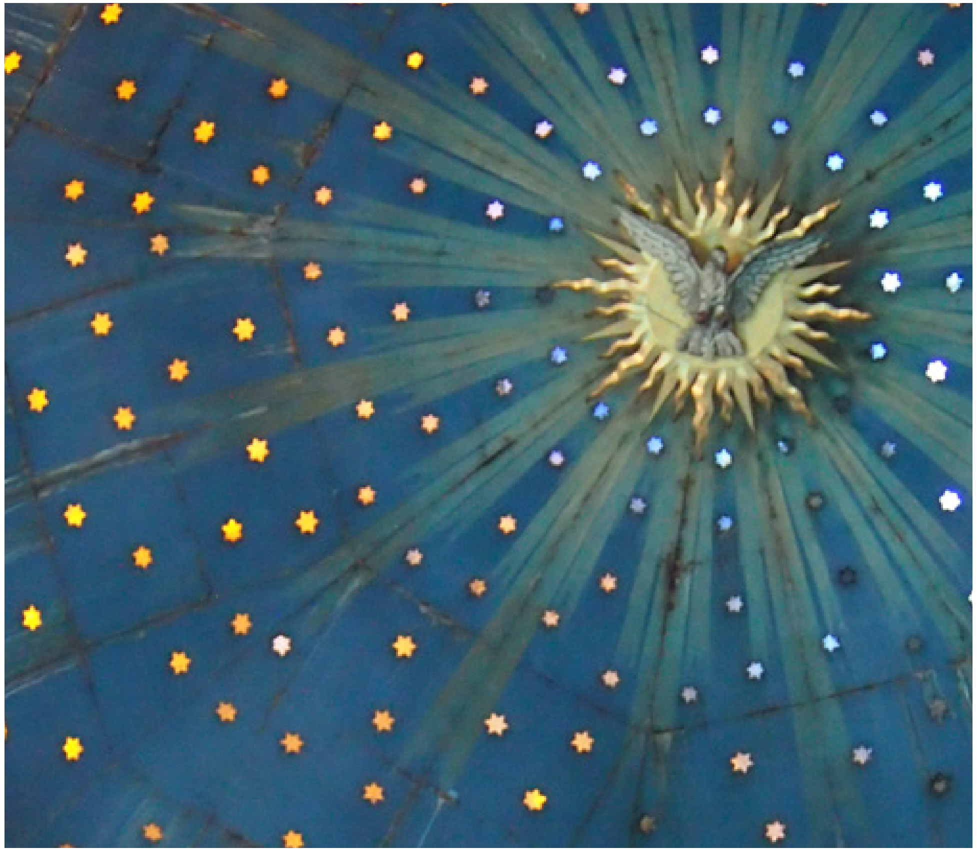
Notes

1 E. W. Skerrey (1982), *Long-Term Atmospheric Performance of Aluminum and Aluminum Alloys*, Wiley, New York, pp. 329–330.

Fig 4.5 [previous pages] The internal cladding of the octagonal dome of San Gioacchino is in excellent condition, photographed 2013

Fig 4.6 [below] In the construction of the octagonal dome of San Gioacchino, the panels can be seen internally as well as externally

Fig 4.7 [right] The mill-finish aluminium cladding is in excellent condition, photographed 2013



St Mary the Virgin, Great Warley, Essex, England: Architect Charles Harrison Townsend with Sir William Reynolds-Stevens, 1902

Art Nouveau interior using aluminium

Fig 4.8 St Mary the Virgin, Great Warley, Essex

Date of visit:	6 October 2013
Time of visit:	10am
Visited by:	Michael Stacey
Location:	Great Warley, Essex, England
Year of completion:	1902
Architect:	Charles Harrison Townsend with Sir William Reynolds-Stevens, sculptor and interior designer
Owner/client:	Church of England
Weather:	Overcast and dry
Access:	Unrestricted access
Materials and finish:	Aluminium leaf

St Mary the Virgin is a Grade I listed Church of England parish church in Great Warley, Essex, England. It is typologically identical to a parish church in Godalming, Surrey; however, it does not feel like a pastiche. The architect Charles Harrison Townsend followed

Fig 4.9 The altar of St Mary the Virgin

the theoretical advice of Aldo Rossi and reused a successful typology, which now sits handsomely in a mature English pastoral landscape. What is truly remarkable about this project is the collaboration between the architect and the interior designer and sculptor Sir William Reynolds-Stevens.[1] This is one of only three Art Nouveau church interiors in the UK. Clearly, the collaboration was close and fruitful. The patron of the church was Evelyn Heseltine, who commissioned it in honour of his late brother Arnold.

The apse of this parish church sparkles with a hemispherical dome clad in aluminium, deployed like gold leaf. This is offset by vine leaves embossed in aluminium and cherry-red grapes. The nave is articulated by arches, which are decorated with embossed aluminium. These organic bas-reliefs are all signed by Sir William Reynolds-Stevens.

Fig 4.10 The pulpit of St Mary the Virgin

Fig 4.11 The hemispherical aluminium-clad dome behind the altar of St Mary the Virgin

Fig 4.12 The nave of St Mary the Virgin

The Arts and Crafts influence on this interior, which existed in parallel to Art Nouveau with considerable cross-influences, can be seen in the use of a range of other metals, in particular beaten copper for the pulpit and brass and even mother of pearl in the rood screen. A. L. Baldry's review of this church in Studio magazine (1905) considered aluminium to be an appropriate and durable component of this material palette.[2]

Possibly because of the expense of aluminium production before the Hall–Héroult process, patented in the USA and France almost simultaneously in 1886, fine art and the decorative arts arguably pioneered the use of aluminium in art, architecture and urban infrastructure. Alexander and Street cite Napoleon III's all-aluminium dinner service,[3] whilst the oldest known sculpture is a one-third size copy of a classic marble sculpture, named Diane de Gabies as it was rediscovered in Gabies in Italy. The aluminium version was produced by Fabrique d'Aluminium, Paul Morin & Cie in Nanterre, France, between 1858 and 1860.[4]

This sculpture predates the more famous cast aluminium pyramid that caps the Washington Monument, completing its construction in 1884. This aluminium pyramid also serves as the point of the lightning conductor of this highly symbolic American monument. Nine years later, in 1893, the cast aluminium sculpture of Eros by Sir Alfred Gilbert, dedicated to Lord Shaftsbury, was erected at Piccadilly Circus, London.

Notes:

1 A. L. Baldry (1905), *A notable decorative achievement by W. Reynolds-Stephens*, The Studio, 34(143), pp. 3–15.

2 Ibid.

3 W. Alexander and A. Street (1944), *Metals in the Service of Man*, 6th edition (1977), Penguin, London, p. 181.

4 D. Harris, *The World's Oldest Aluminium Casting*, available online at www.dcsoc.org.uk/filemanager_net/files/The_Worlds_Oldest_Aluminium_Castings.pdf (accessed August 2013).

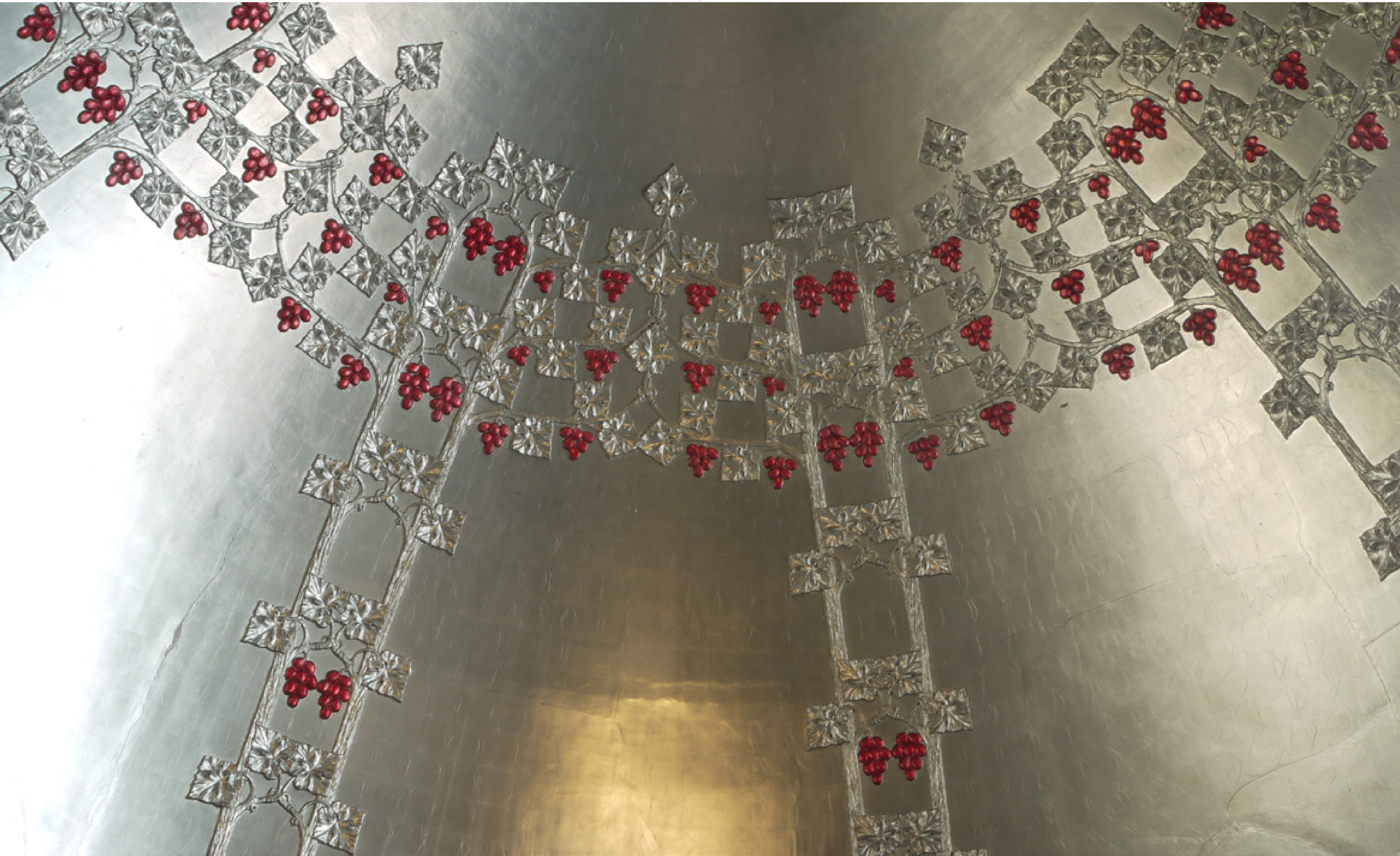


Fig 4.13 Detail of the hemispherical dome behind the altar of St Mary the Virgin

Fig 4.14 Decorative embossed aluminium cladding of the arches spanning the nave of St Mary the Virgin

Fig 4.15 Detail of the aluminium embossed decoration of an arch

Postsparkasse, Vienna, Austria: Architect Otto Wagner, 1906

First world-class project to use aluminium

Fig 4.16 Postsparkasse designed by Otto Wagner, viewed from Georg-Coch-Platz

Date of visit:	7 October 2013
Time of visit:	10am–1pm and 2pm–4pm
Visited by:	Michael Stacey
Location:	Vienna, Austria
Year of completion:	1906
Architect:	Otto Wagner
Owner/client:	Austrian Postal Savings Bank
Weather:	Overcast and dry
Access:	Inside and outside
Materials and finish:	Constructed using numerous aluminium components, mill-finished sheet inside and out, with cast aluminium sculptures

Otto Wagner's Postsparkasse [Postal Savings Bank] in Vienna is one of the masterpieces of early twentieth-century architecture. Nikolaus Pevsner considered that this building demonstrated an

'artistic economy and clarity, of which there is virtually no parallel in this period', viewing it as exemplary of the development of modern architecture.[1] Famous for the use of aluminium in its façades, it was the first example of a world-class work of architecture that used aluminium extensively in its construction, interior and furnishings, at a time when the total world production of aluminium was only 6,000 tonnes.[2]

The Austrian Postal Savings Bank was founded by Dr Georg Coch-Platz in 1893 based on the model of British savings banks. It rapidly became very successful and outgrew the rooms provided for it in a Dominican monastery in Vienna. This resulted in a competition in 1903, won by Otto Wagner. The site, a complete city block just

Fig 4.17 4.5m high cast aluminium sculpture of an angel or Winged Victory standing on the projecting cornice

inside the Ringstrasse in Vienna city centre, had previously been identified by Wagner as the site for a bank in his strategic plan for the development of Vienna in 1892.

The cornice of the entrance façade is completed by 4.5m-high cast aluminium sculptures in the form of winged female figures, possibly Victories, by the sculptor Othmar Schimkowitz. He also sculpted the six cast aluminium swags and laurel wreaths at the corners of the bank. In the same year that Otto Wagner won the Postsparkasse competition in Vienna, 1903, proposing the extensive use of aluminium, in the USA the Wright brothers, Orville and Wilber, achieved the first powered flight, in the Wright Flyer. This aircraft was powered by a petrol engine, with a lightweight cast aluminium engine block. This reveals that the benefits of aluminium were being taken up in many fields of human endeavour, including architecture and transport, effectively at the same time.

The frieze above the entrance facing the Ringstrasse is filled by the name of the bank, *Österr. Postsparkasse:*, in delightful Art Nouveau lettering, punched from aluminium sheet. The steel columns supporting the scalloped translucent glass canopy sheltering the entrance are clad in aluminium. The head and base of the cladding are formed from aluminium spinnings. Of these six columns, the aluminium cladding of one has become wrinkled near the base and another has a slight split. Generally, however, their condition is excellent given that they were 107 years old, older than the definition of an antique, when inspected in 2013.

The construction of the Postsparkasse began on 12 July 1904 and was completed in 16 months. A key to delivering this speed of construction was the bolted cladding of 100mm thick granite to the base and first floor and 20mm thick Sterzing marble for the next four floors and cornice. Siegfried Gideon believed that the façades were fixed with aluminium bolts. He observed that Otto Wagner 'strongly stressed the function of the wall as a plain surface. The façade of this building is clad with marble panels; and these are fastened down with solid aluminium bolts, the heads of which

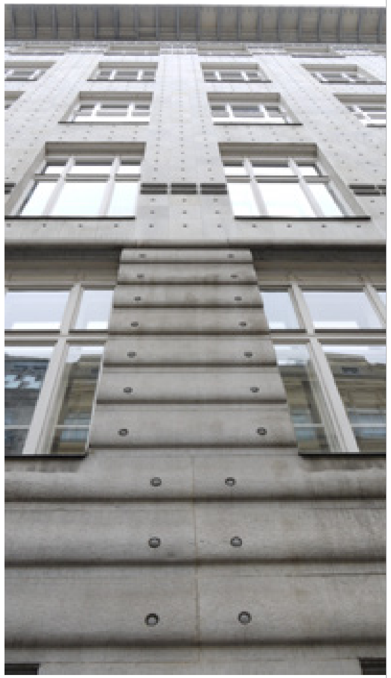


Fig 4.18 Detail of Postsparkasse façade

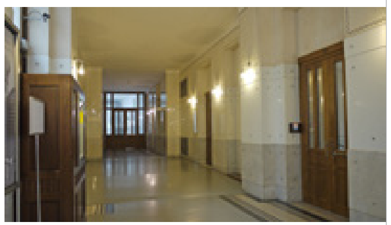


Fig 4.19 The steel bolts protected from corrosion by lead with aluminium caps, are also used in the interior

Fig 4.20 [left] Aluminium-capped bolts showing the longevity of aluminium compared to the rusted steel

Fig 4.21 [right] Detail of the connection between the first and second phase of the bank

are clearly visible.'[3] The 17,000 bolts used in the façade are steel protected from corrosion by lead with aluminium caps. Wagner selected this technique to facilitate rapid construction; he also thought that the layered façade referred back to the cladding of buildings such as the Pantheon in ancient Rome, where marble was used as a facing to brickwork. This was characteristic of Otto Wagner's approach to architecture after the publication of his book *Modern Architecture* in 1895; [4] he embraced tradition and change, working with clarity within the city, yet using modern materials, particularly aluminium, which was almost unknown in architecture at the time. The central portion of the marble façade above the entrance is more densely studded with aluminium-capped bolts to emphasis the entrance. Wagner consciously referenced a strongbox or treasure chest as a metaphor for a reliable bank. Popularly, the building soon became known as 'the Pincushion'. Three years from competition to completion remains a tight timescale for the delivery of a major work of architecture in the twenty-first century.

The plan of the Postsparkasse has a simple directness that makes it readily navigated by customers. The central space is the main banking hall, which has a glass floor to provide light to the floor below and has a glass and steel double roof. The inner layer of the roof is made of translucent glass that provides a gentle and even daylight. This space was originally warmed by the tubular aluminium heaters clearly articulated from the walls. Following the

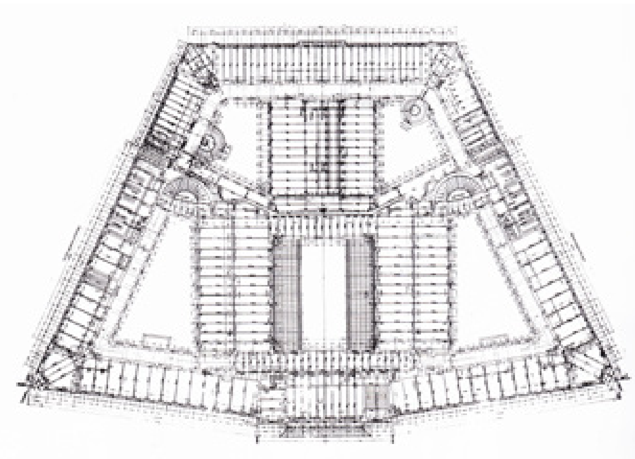


Fig 4.22 Ground floor plan of Postsparkasse by Otto Wagner

Fig 4.23 [right] Aluminium heaters now functioning as air extractors

refurbishment of the building in 1995, these have been converted into air extractors; in essence, they retain their original role. Wagner's warm air heaters of this banking hall form the inspiration for the heaters of the car showroom and restaurant of the Renault Centre in Swindon, England, by Foster Associates, which was formally opened in 1983.[5] The steel columns of the banking hall are clad in aluminium. This cladding was removed during the restoration work in 1995 to enable the corroded steel to be treated and painted. The aluminium cladding was simply cleaned and reinstated.[6]

Fig 4.24 [left] Postsparkasse: the main banking hall

Fig 4.25 [right] Aluminium-clad columns and aluminium handrails of the entrance

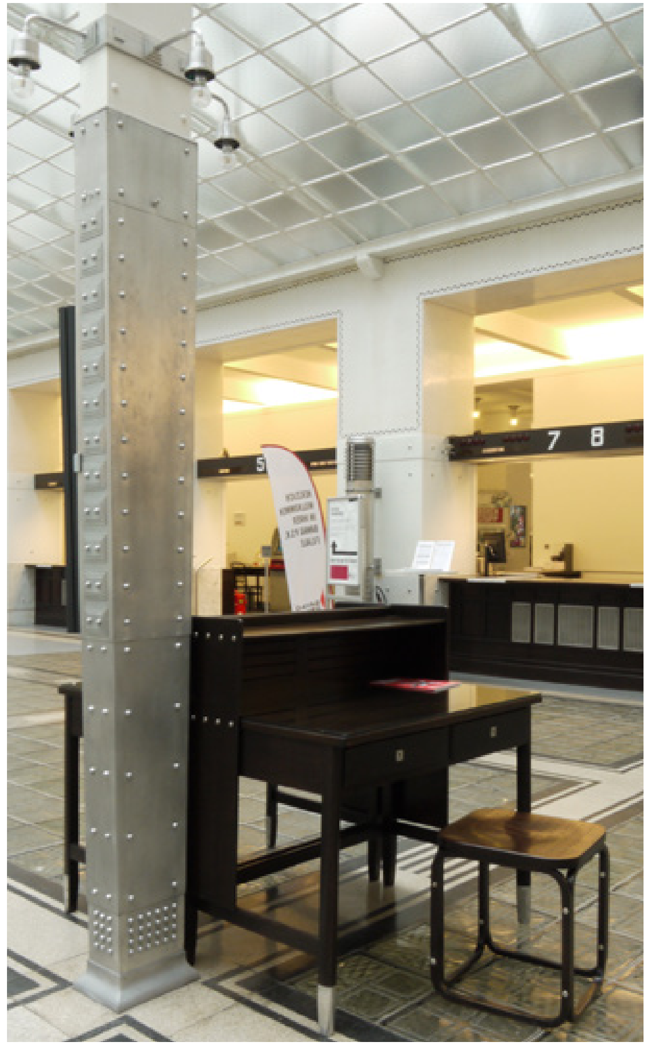
Fig 4.26 [above] The aluminium cladding has wrinkled at the base of one entrance canopy column

Fig 4.27 [left] Spun-aluminium base detail of an entrance canopy column

Fig 4.28 [right] Aluminium cladding protecting the internal structural column. Aluminium footings added to the chairs and tables throughout the Postsparkasse emphasise the durability of aluminium

The Postsparkasse is an exemplar of *Gesamtkunstwerk*, a total work of art. Wagner engaged in designing everything in the bank from carpets and counters to clocks. All of the interiors, including furnishings and fittings, were designed by Otto Wagner's office. A total of 800 aluminium door latches were used throughout the bank. He made Thonet bentwood chairs more durable by the use of aluminium feet and articulated the function and structure of the chairs with further aluminium details.

The Postsparkasse was completed in 1906, less than 100 years after the discovery of aluminium in 1808 by Sir Humphry Davy in the UK.[7] Although aluminium was a new material to architecture, at the turn of the nineteenth century Otto Wagner had a very clear idea of its durability. Did this reflect his own observations of samples or



was he advised by scientists at Austrian universities? At the end of the nineteenth century, Vienna was noted as a city transformed by science. Otto Wagner was linked to this intellectual community as he taught architecture and was Professor of Architecture at the Vienna Academy of Fine Art. Not surprisingly, following the success of the Postsparkasse, Otto Wagner used aluminium on subsequent projects in Vienna including the Döblegergass 4 apartment building (1912) and the Second Wagner Villa (1913). Jan Tabor observes that Wagner's use of aluminium on the Postsparkasse was 'an unusual building material at the time – and even today'.[8]

The second phase of the Postsparkasse, completing the block on Dominikanerbastei, was built between 1910 and 1912. The façade tectonic is essentially similar with a granite-clad base and marble cladding above, all articulated with aluminium-capped bolts. However, Wagner chose to express the new extension via a shadow gap between the two phases and by simplifying the cladding into flat planes.

Otto Wagner thought that 'what is impractical cannot be beautiful',[9] a lesson many contemporary digital architects could learn from. Otto Wagner's design for the Postsparkasse represents a crux in the history of aluminium in architecture. With its cast aluminium sculptures and decorative sensibility, it is part of the early decorative use of aluminium, be this Eros at Piccadilly Circus in London (1893), San Gioacchino in Rome (1897), or St Mary the Virgin in, Great Warley, Essex, England (1905).[10] This was a phase in which aluminium was enjoyed as an exotic and rare material. The Postsparkasse, however, also signifies the start of the use of aluminium as an affordable, durable and repeatable building component, where components are used hundreds or even thousands of times to produce architecture of the highest quality, delivered by economical and rapid construction processes.

Notes:

1 N. Pevsner, J. Fleming and H. Honour (1971), *Lexikon der Weltarchitektur*, Prestel, London, p. 618.

2 J. Tabor (1996), *Otto Wagner: Die Österreichische Postsparkasse*, Falter Verlag, Vienna, pp. 36–37.

3 S. Giedion (1941), *Space, Time and Architecture: The Growth of a New Tradition*, Harvard University Press, Cambridge, MA, p. 218.

4 O. Wagner (1896), *Moderne Architektur*, Verlag vaon Anton Schroll & Co., Vienna.

5 M. Pawley (1983), *New age detailing at Renault by Foster*, Architects' Journal, 15 June, pp.40-45. In 2013, the Renault Centre was made a Grade II listed building.

6 Exhibition in the *Wagner: Werk Museum Postsparkasse*, which is located behind the main banking hall., visited 7 October 2013.

7 Sir Humphry Davy identifies aluminium as a constituent of alumina – see H. Davy (1808), *Electro Chemical Researches, on the Decomposition of the Earths; with Observations on the Metals obtained from the alkaline Earths, and on the Amalgam procured from Ammonia, Philosophical Transactions of the Royal Society*, London, p.353.

8 J. Tabor (1996), *Otto Wagner: Die Österreichische Postsparkasse*, Falter Verlag, Vienna, pp. 36–37.

9 O. Wagner (1896), *Moderne Architektur*, Verlag vaon Anton Schroll & Co., Vienna. In 1900, Albert Einstein stated: 'A formula without beauty cannot be right'. Both quotations are cited in J. Tabor (1996), *Otto Wagner: Die Österreichische Postsparkasse*, Falter Verlag, Vienna, p. 4.

10 An earlier dome clad in aluminium was to be found in Sydney, Australia on the Colonial Secretary's Building. James Barnet designed this project in 1873; however, the dome was added between 1896 and 1898 under the design direction of Walter Liberty Vernon. The aluminium was apparently replaced during a refurbishment of the building by Jackson Teece Chesterman Willis in 1994.

Fig 4.29 [right] A corner of the Postsparkasse

Fig 4.30 [next page] View of Georg Coch sculpture in Georg-Coch-Platz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Aluminium Centenary Pavilion, Paris, France: Engineer/Fabricator Jean Prouvé, 1954

Pioneering and celebratory project

Date of visit:	16 October 2013
Time of visit:	10.30am
Visited by:	Michael Stacey Architects
Location:	Villepinte, Paris, France
Year of completion:	1954
Engineer/fabricator:	Jean Prouvé
Owner/client:	Realty Corporation for the construction of the Palais des Congrès [SIPAC]-since 1998[1]
Weather:	Overcast and dry
Access:	Unrestricted external access
Materials and finish:	Formed from almost entirely aluminium components: folded sheet, extrusions and castings, plus glass

Jean Prouvé's Aluminium Centenary Pavilion was built in 1954 to celebrate the 100th anniversary of the industrial production of aluminium in France by l'Aluminium Français. The purpose of the pavilion was to demonstrate the possibilities of aluminium

Fig 4.31 Aluminium Centenary Pavilion, photographed 2013 at Villepinte

Fig 4.32 Detail of the façade

in construction and to promote its wider use; Prouvé did this by combining forms of aluminium, such as folded sheet, extrusions and castings. Prouvé is known for his ability to intelligently connect a material's capability to an aesthetic born of a construction logic.[2] Much of his career was dedicated to designing lightweight building systems that were easy to fabricate and construct. The Aluminium Centenary Pavilion is one of Prouvé's most ambitious works and is a key building in his manifesto of early high-tech architecture. Sixty years on from its initial conception, the pavilion's structural use of aluminium is still an exemplar of how it can replace steel, timber and other construction materials.

Designed as an exhibition hall, the pavilion is a seminal example of Prouvé's preoccupation with lightweight metal architecture. The pavilion was designed and manufactured as a 152m-long structure with a frame spanning 15m, placed at 1.34m. The folded-sheet aluminium roof beams were made in three parts, assembled with cast brackets, which attach to extruded aluminium vertical columns, many of which also act as glazing mullions. The façade panels were the only part of the pavilion manufactured from pure aluminium; all but one of the subtly corrugated sheets with calotte-shaped dents have been lost in its three relocations.

Fig 4.33 Poster for the 1954 *L'exposition de L'aluminium*

The pavilion was originally erected in 1954 on the banks of the River Seine in central Paris. In 1955, it was disassembled into components and transported by barge to Lille, where it was bolted onto an existing exhibition hall. The pavilion underwent an unrecognisable reconfiguration into an L-shaped plan with beige timber cladding.

The inclusion of the pavilion in the *Supplementary Inventory of Historical Monuments* in 1993 saved it from irremediable destruction. Architecture-Studio [AS] carried out the reconstruction and restoration of the pavilion from disassembly in 1993 to reconstruction in 1998, when it was moved to its current location at Villepinte, near Charles de Gaulle Airport, a large exhibition site with eight halls. The reconstruction cost €640,000 and the pavilion had to be shortened to 90m due to the availability of original parts after disassembly, reducing the overall area from 2,250m^2 to 1,350m^2.

Prouvé grew up in Nancy, a city in north-east France, known as a centre for the blacksmith trade and the steel industry. Due to his family not being able to support him financially, Prouvé was unable to study his dream profession of engineering and instead became an apprentice blacksmith for the artist Emile Robert. To further this training, Prouvé then chose to study with one of the leading artistic blacksmiths, Adalbert Szabo. It was this craftsman training that led Prouvé to cognitively experiment with aluminium on both a macro and micro scale.

Folding is a fundamental metalworking technique, which Prouvé first experimented with in a series of tables he designed shortly after his apprenticeship. The structural lightness of these tables is evidently continued into the Aluminium Centenary Pavilion in the aluminium beams. These beams are folded from sheet aluminium into U-shaped hollow ribs; the folding enhances the stability and maximises the strength of thin sheet metal. This principle is easy to comprehend when comparing corrugated metal to sheet metal. Prouvé mastered simplicity, ensuring every element works to its highest capability. The folded metal beams double as gutters with cambered roof sheets attached between them with riveted connections.

Fig 4.34 Cast aluminium brackets unite beams and extruded aluminium mullions

Fig 4.35 Internal view of the structure meeting the glazing

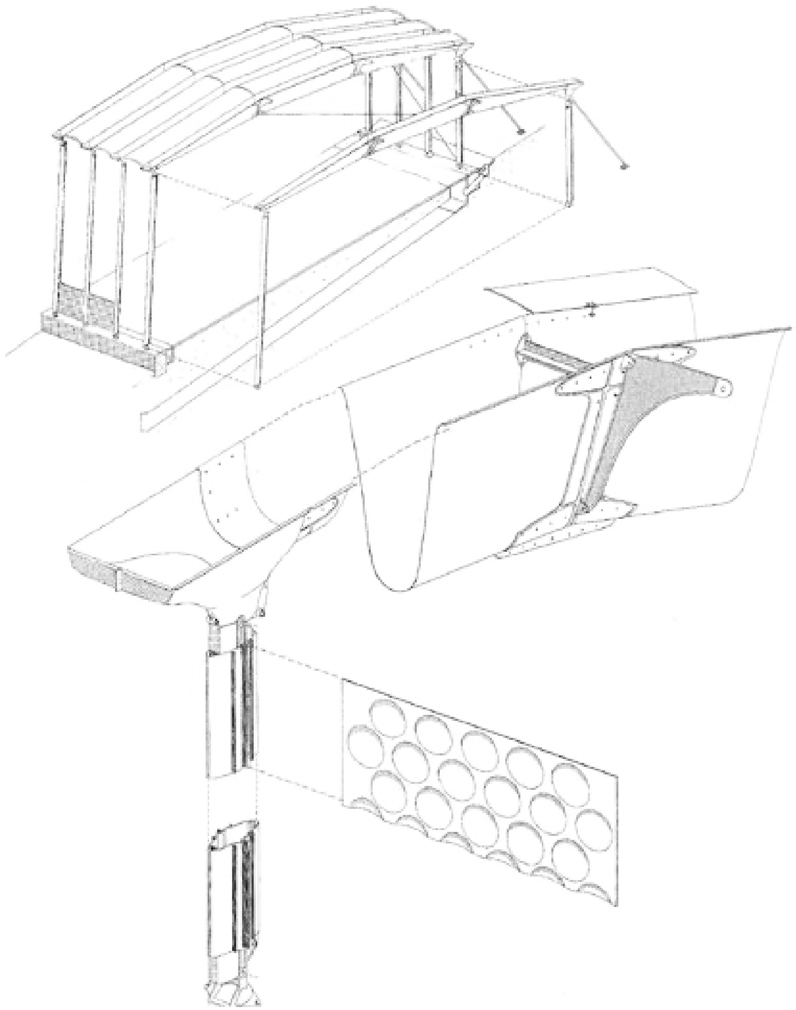


Fig 4.36 Detailed axonometric drawing of the aluminium frame

Fig 4.37 Cast aluminium footings of the Aluminium Centenary Pavilion

To deal with issues of prefabrication, the beams were manufactured in three parts and transported to site where they were connected with cast aluminium brackets. The brackets are also U shaped and cradle the folded beams. There is a horizontal connection at the top of the U to secure the overlapping folded-beam sections and ensure rigidity. These brackets also provide a shelf to support the roof sheets.

The two relocations of the pavilion verify the logic of a prefabricated modular building system; Prouvé produced a mobile architecture that can be demounted, relocated and reused. Although aluminium is almost infinitely recyclable, the Aluminium Centenary Pavilion demonstrates that reuse is a better option.

Notes:

1 The Aluminium Centenary Pavilion was commissioned by l'Aluminium Français in 1953. It was then bought by André Lannoy Sr and André Lannoy Jr of Vitralu, in 1956 and sold to Realty Corporation for the construction of the Palais des Congrès (SIPAC) in 1998, who commissioned the restoration and reconstruction in Villepinte.

2 N. Peters (2013), *Jean Prouvé: 1901–84: The Dynamics of Creation*, Taschen, Cologne, p. 7.

FIVE

aluminium and durability case studies

Aluminium and Durability Case Studies

This chapter progresses to a more contemporary history of the use of aluminium in architecture. The buildings were selected on the basis that they are award-winning or historically important works of architecture incorporating a significant use of aluminium. These projects are primarily in the UK, with one in the USA, and the completion dates range from 1938 to 1990. These buildings were visited between the spring of 2012 and summer of 2013. There is an intended overlap with the projects included in Chapter Four. To be able to examine the durability of aluminium used to make architecture, the youngest project selected is over 20 years old. All of the projects are older than the known guarantees offered on the specified aluminium finishes when they were constructed. These buildings range in typology from a university library, through offices, industrial and retail buildings to houses, showing that aluminium is used in all sectors of contemporary construction. This chapter concludes with a summary of the principles underlying the durability of aluminium in architecture derived from the 12 case studies and related literature review.

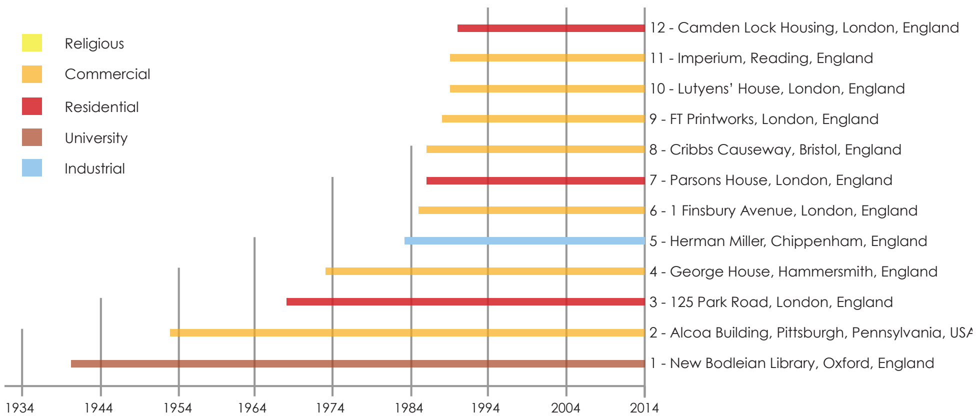


Fig 5.0 Graph showing the age and typology of the case studies included in this chapter

Fig 5.1 [right] New Bodleian Library on Broad Street Oxford, photographed shortly after it reopened in 2015, architect of the refurbishment WilkinsonEyre, note the original anodised aluminium windows, which were made before 1940

Initial Case Studies

No.	Project	Architect	Date	Client Current	Location	Aluminium Finish	Condition	Inspected
1	**New Bodleian Library**	Sir Giles Gilbert Scott	**1940**	University of Oxford	Oxford, UK	Silver anodised	Anodised aluminium windows in excellent condition, Library being refurbished by WilkinsonEyre	8.4.2013 Michael Stacey
2	**Alcoa Building**	Harrison & Abramovitz	**1953**	PMC Property Group	Pittsburgh, USA	Silver anodised	Excellent exemplar – untouched, 30-storey Alcoa Building in Pittsburgh built between 1951 and 1953 and clad in unitised curtain walling with openjointed aluminium baffle panels.	25.6.2013 Stephanie Carlise
3	**125 Park Road**	Farrell and Grimshaw	**1968**	Mercury Housing Society Ltd	London, UK	Silver anodised	Good condition, but dirty some dents on lowest panels	27.5.2012 Michael Stacey
4	**George House**		**1973**	Hammersmith Grove Property Investment Ltd	London, UK	PPC	Good condition	5.5.2013 Toby Blackman
5	**Herman Miller Distribution Centre**	Nicholas Grimshaw & Partners	**1983**	Herman Miller	Chippenham, UK	PPC (East Façade only)	Very good condition in view of its age – minimal filiform corrosion of panels	20.4.2013 Michael Stacey
6	**1 Finsbury Avenue**	Arup	**1985**	UBS	London, UK	Bronze anodised	Very good condition, however, some apparent end corrosion observed	27.5.2012 Michael Stacey
7	**Parsons House**	Peter Bell & Partners	**1986**	Westminster City Council	London, UK	PPC	Good condition – panels better than windows, some corrosion at window mitres and drainage slots on some windows	27.5.2012 Michael Stacey
8	**Cribbs Causeway**	BDP	**1986**	Prudential Assurance Company	Bristol, UK	PPC with PVDF on galvanised steel	Expanded and superficially altered	20.4.2013 Michael Stacey
9	**Financial Times Printworks**	Nicholas Grimshaw & Partners	**1988**	Global Switch	London, UK	PVDF and silver anodised	Very good condition – only very limited mechanical damage	27.5.2012 Michael Stacey
10	**Lutyen's House**	Sir Edwin Lutyens and Brookes & Stacey	**1989**	Cisco	London, UK	PPC	Good condition despite no sign of cleaning	27.5.2012 Michael Stacey
11	**Imperium**	Bennetts Associates	**1989**	M & G Real Estate	Reading, UK	PPC	Good condition and PPC has and even finish and high level of gloss retention	5.5.2013 Michael Stacey
12	**Camden Lock Housing**	Nicholas Grimshaw & Partners	**1990**	Private ownership	London, UK	PVDF	Dirty – potentially never cleaned for 22 years	14.4.2012 Michael Stacey

Notes
1 PPC is polyester powder coating
2 PVDF is polyvinylidene fluoride coating

New Bodleian Library, Oxford, England: Architect Sir Giles Gilbert Scott, 1940

Fig 5.2 New Bodleian Library on Broad Street, Oxford, photographed shortly after it opened in August 1940

Date of visit: 8 April 2013

Time of visit: 11am

Visited by: Michael Stacey

Location: Broad Street, Oxford, England

Year of completion: 1940

Architect: Sir Giles Gilbert Scott

Owner/client: University of Oxford

Weather: Cloudy and dry

Access: Unrestricted access (noting that a the time of inspection the library was a building site)

Materials and finish: Silver anodised aluminium windows

Case Study Data

The New Bodleian Library was designed by Sir Giles Gilbert Scott and built between 1936 and 1940 as a much-needed addition to the Bodleian Library, whose collections are used by academics and scholars from around the world. It opened in August 1940 to

mixed reviews from J. M. Richards (under the pseudonym James MacQueady) and Nikolaus Pevsner.[1] It was however Grade II listed on 1 September 2003 and this listing by English Heritage (now Historic England) records the use of aluminium alloy windows, but not the finish.[2] Toby Kirtley of Oxford University Estates observed how reliable these windows had proved in over 70 years of use.[3] Clearly, Sir Giles Gilbert Scott had used the same specification for the windows as at the University of Cambridge Library (1934); see page 40. Once again, the aluminium windows were manufactured by James Gibbons of Wolverhampton.

Observations

It had been suggested that the windows were mill-finish aluminium; however, on inspection they appeared to be silver anodised, but in need of cleaning. At the time of inspection the library was being refurbished under the design leadership of architect WilkinsonEyre and the contractor was MACE. Some windows had been removed and stored to facilitate access to the interior. The windows are single glazed with solid aluminium sections and generally appeared to be in very good condition, confirming the earlier report from Estates. The anodised aluminium windows appeared to be the only use of aluminium in the construction of this building, which combines stripped modernism with specific classical details.

Initial Further Research Actions

A. A good candidate for non-destructive testing, as it is one of the oldest extant examples of anodising and architect WilkinsonEyre was leading the refurbishment of the library.

Notes

1 J. MacQueady (1940), *Gilbert Scott's New Bodleian Library*, Architectural Review, October, (Editor J. M. Richards, under the pseudonym James MacQueady). J. Sherwood and N. Pevsner (1974), *The Buildings of England: Oxfordshire*, Yale University Press, New Haven, p. 263.

2 New Bodleian Library: Historic England List Entry Number 1390596 (accessed April 2013).

3 J. Ratcliffe ed., (2008), *Aluminium and Sustainability: Cradle to Cradle*, Council for Aluminium in Building, Stonehouse, p. 17.

Alcoa Building, Pittsburgh, Pennsylvania, USA: Architect Harrison & Abramovitz, 1953

Date of visit:	25 June 2013
Time of visit:	11am – 2pm
Visited by:	Stephanie Carlisle
Location:	425 Sixth Avenue, Pittsburgh, Pennsylvania, USA
Year of completion:	1953
Architect:	Harrison & Abramovitz
Owner/client:	PMC Property Group
Weather:	Sunny and warm
Access:	Unrestricted access to the exterior; limited access to interior including 22, 28 and 30 floors
Materials and finish:	Unitised anodised aluminium curtain walling. Interiors: aluminium sheet wall covering, window cills, perforated ceiling panels, woven aluminium mesh and other detailing

Case Study Data

This 30-storey aluminium-clad tower was designed by Harrison & Abramovitz and constructed between 1951 and 1953. The Alcoa Building originally served as the headquarters for the Alcoa Corporation. For more information on the design and construction of 'the world's first aluminum skyscraper', see pages 61–63. When Alcoa moved its headquarters to larger office space in Pittsburgh's North Shore in 2001, the building was donated to the Southwestern Pennsylvania Commission. The building was renamed the Regional Enterprise Tower and intended to be used as a central location for many community support organisations and local NGOs. In the spring of 2013 the building was sold to PMC Property Group, a private developer, who intend to introduce mixed uses into the building, including apartments.

Observations

Fig 5.3 The rich patina of the anodised aluminium curtain walling of the Alcoa Building, Pittsburgh, designed by Harrison and Abramovitz completed in 1953, photographed 2013

The aluminium cladding has developed a deep patina and weathered in an attractive manner over the last 50 years with minimal, if any, maintenance to the building envelope. There was no evidence of cleaning on any of the façades; some staining and discoloration was observed on the first-floor window mullions at joints and seams, leading to staining on adjacent granite. Each panel is a single storey tall (inclusive of spandrel) with rounded windows set within the pressed form. The forming of the metal has resisted dirt deposits and staining, unlike several nearby aluminium-clad buildings that have not fared as well. Some minor staining was visible around the perforated vent screens on the side of the building from mechanical exhaust and venting of the loading dock.

All windows on the building are reported to be original. The windows on all office levels were manufactured by the Adam & Westlake Company in Elkhart, Indiana. The windows are beautifully designed, with a centre pivot enabling the windows can be cleaned from inside. The windows have a locking mechanism on each lower corner and are sealed with a pneumatic gasket within the mullion, which allows the window to turn when deflated. The nozzle for operating the windows is within the knob.

Fig 5.4-Fig 5.5 [below and right] The Adlake aluminium windows of the Alcoa Building were fabricated by Adams & Westlake, who also manufactured aluminium railway cars (coaches)

The only visible wear on the windows is the rubber gasket and seal on the interior. According to a long-term building occupant, there was a stockpile of extra rubber seals in the basement, but these have decayed over time in storage. Although Adam & Westlake are still in business working with aluminium it no longer manufactures windows.

Initial Further Research Action

A. A potential candidate for non-destructive testing, which is proposed as a follow up to the initial UK-based testing.

Fig 5.6 125 Park Road, London, architect Farrell and Grimshaw, 1968: silver anodised cladding and windows

125 Park Road, London, England: Architect Farrell and Grimshaw, 1968

Fig 5.7 Detail of silver anodised cladding and windows, 125 Park Road, London, architect Farrell and Grimshaw

Date of visit:	27 May 2012
Time of visit:	2pm
Visited by:	Michael Stacey
Location:	125 Park Road, Regents Park, London, England
Year of completion:	1968
Architect:	Farrell and Grimshaw
Owner/client:	Mercury Housing Association
Weather:	Sunny and dry
Access:	Unrestricted access to the exterior only
Materials and finish:	Silver-anodised aluminium profiled sheeting with curved corners and silver-anodised aluminium windows

Case Study Data

Designed by Nicholas Grimshaw with Paul Gibson and Graham Sounders of Farrell and Grimshaw, this apartment tower is on an excellent site overlooking Regents Park in central London. The 12-storey tower is square on plan with rounded corners. The apartments were designed to offer maximum flexibility, from bedsits to complete open-plan penthouses. This is based around

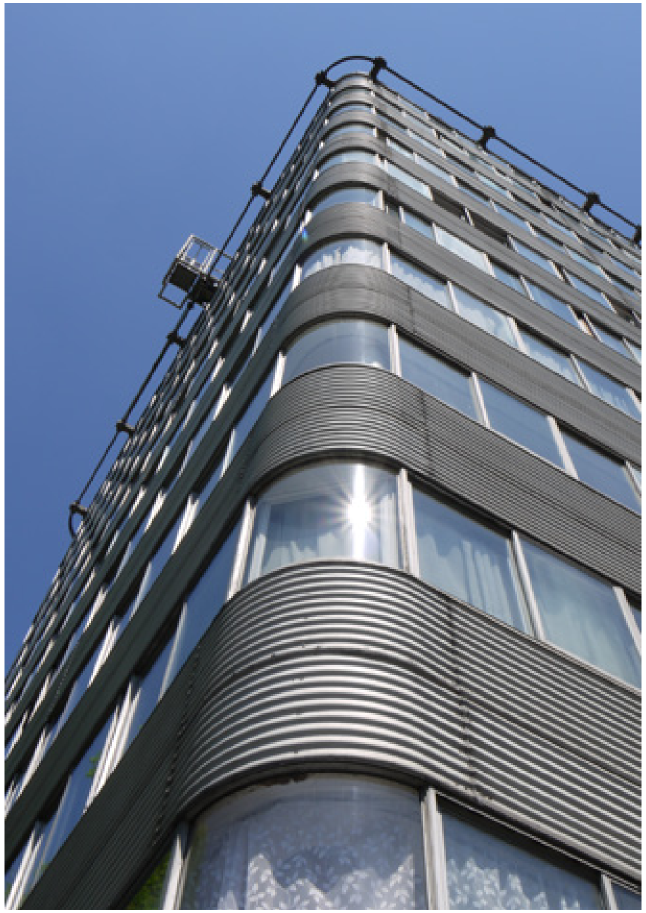


Fig 5.8 Curved corner of 125 Park Road: note the cleaning access system

four cores, two with bathrooms, one with lifts and one with a fire-protected escape staircase, with concrete columns only near the perimeter of the plan offering column-free living spaces. The ribbon windows facilitate the placement of internal partitions in a wide range of locations. The internal walls of the apartments were specified and in some cases constructed by the original tenants themselves. The anodised aluminium cladding and windows were specified as they 'have the benefit of very low maintenance'.[1] The anodised aluminium profiled cladding could also be readily curved to form the corners of the apartment tower.

Observations

This is very successful housing in an excellent location in central London. Affordable housing of this quality should be the norm and not the exception. The tower is in very good condition despite being 24 years old when inspected. Although a cleaning access

Fig 5.9 Silver anodised aluminium ribbon windows and cladding

system is provided at eaves level, this appears to have only been used for window cleaning. There is no evidence that the anodised aluminium profiled sheeting has ever been cleaned. However, it remains silvery grey in appearance. The curved corners of the anodised profiled sheet aluminium work very well with the curved glass of the corner windows. Perhaps the architects would be less keen on the lace curtains that many occupants appear to have installed, even though there is little sense of the tower being over-looked.

All of the details are in essence standardised until the penthouse level, creating a simple and direct yet pleasing rhythm to the elevations. The details are well conceived and generally well executed. Only a few trim details revealed any sign of ageing; primarily, this is due to standard steel screws, which are corroding and were used either in the original construction or during maintenance.

Initial Further Research Actions

A. Potential candidate for non-destructive testing.

Note

1 N. Grimshaw (ed.) (1988), *Nicholas Grimshaw & Partners: Book 1 Product*, NGP, London, p. 13.

Fig 5.10 George House (formerly Wimpey Headquarters), 26–28 Hammersmith Grove, London

Fig 5.11 The façade with polyester powder-coated aluminium windows

Fig 5.12 Detail of a polyester powder-coated aluminium window

George House (formerly Wimpey Headquarters), London, England: 1950s and1973

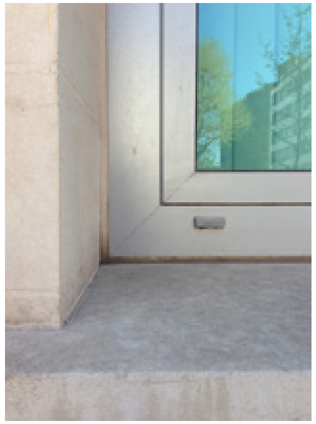


Fig 5.13 Detail of a Syntha Pulvin polyester powder-coated aluminium window

Fig 5.14 Polyester powder-coated aluminium windows

Date of visit: 5 May 2013

Time of visit: 11am

Visited by: Toby Blackman

Location: 26–28 Hammersmith Grove, London, England

Year of completion: 1950s and1973 (aluminium windows)

Owner/client: Hammersmith Grove Property Investments Ltd

Weather: Sunny and dry

Access: Unrestricted access to the exterior only

Material and finish: Syntha Pulvin polyester powder-coated aluminium windows and curtain walling

Case Study Data

George House is a 12-storey office building comprising two distinct structures, or bays, both using reinforced concrete. One was completed in the 1950s and the other in 1973. George House is located on the southern side of Hammersmith Grove, close to the junction with Glenthorne Road. The windows of George House fall into three essential classifications: aluminium casement windows in the stone-clad main building, component (stick-system) cladding which includes glazed and opaque modules, and capless curtain walling forming a more recent addition to the courtyard.

Fig 5.15 Rear extension connection to the original building

Observations

The original aluminium windows (1973) are of sound essential component and assembly design, were clearly installed by a skilled contractor and are evidently being well maintained. The finish is silver anodising. The latter stick-system cladding exhibits less robust detailing in the abutment of elements and planes; soft jointing (silicone mastic) is evident at numerous junctions, which would be better resolved with flashed, lapped or capped assemblies, though the basic, two-dimensional assembly of the cladding is true, and well aligned in plumb, plane and line. The finish is polyester powder coating.

The curtain-walled addition to the courtyard is altogether more sophisticated; the addition is a good example of capless, silicone-jointed curtain walling, detailed and constructed with skill and attention to junctions and abutments.

The building has been subject to incremental alterations to its elevations over a number of years, primarily involving glazing extensions (for example, the curtain-walled addition to the courtyard) and alterations to the windows. Water staining is absent from the anodised aluminium, evidencing a maintenance regime that is appropriate and regularly undertaken.

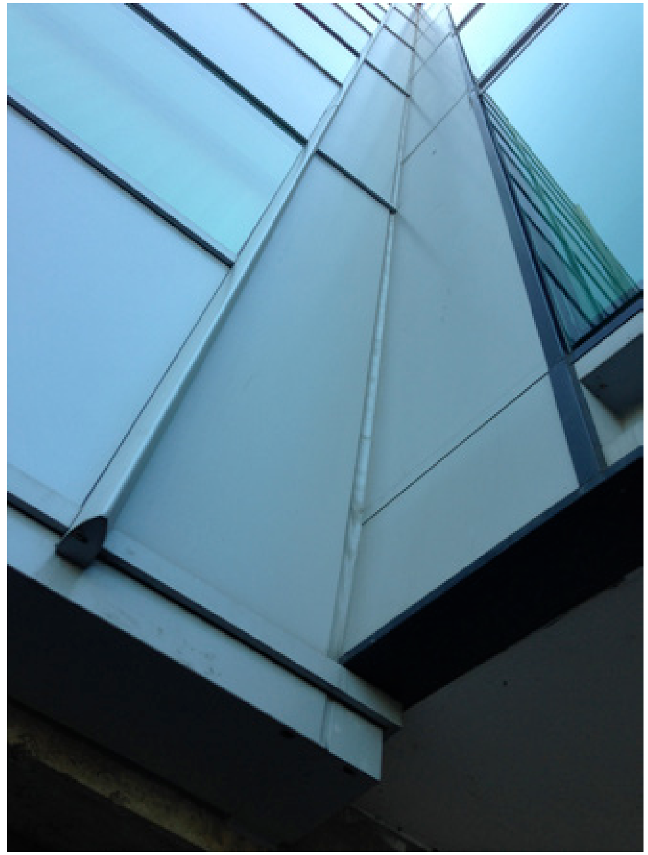


Fig 5.16 Rear extension of George House is clad in Syntha Pulvin polyester powder-coated aluminium curtain walling

The original aluminium windows exhibit little wear or discolouration; the cills, hinges and handles are not contributing to any significant run-off or discolouration of the adjacent stonework, thanks to robust detailing and skilled construction. The stick system is weathering well in the two-dimensional plane, the material finish is consistent and even the capped stick system is not producing significant discolouring run-off. However, the junctions, which are suspended cladding base/undercroft soffit junctions, are not weathering so well, and exhibit discolouration, run-off and some open detailing (i.e. open-ended stick components).

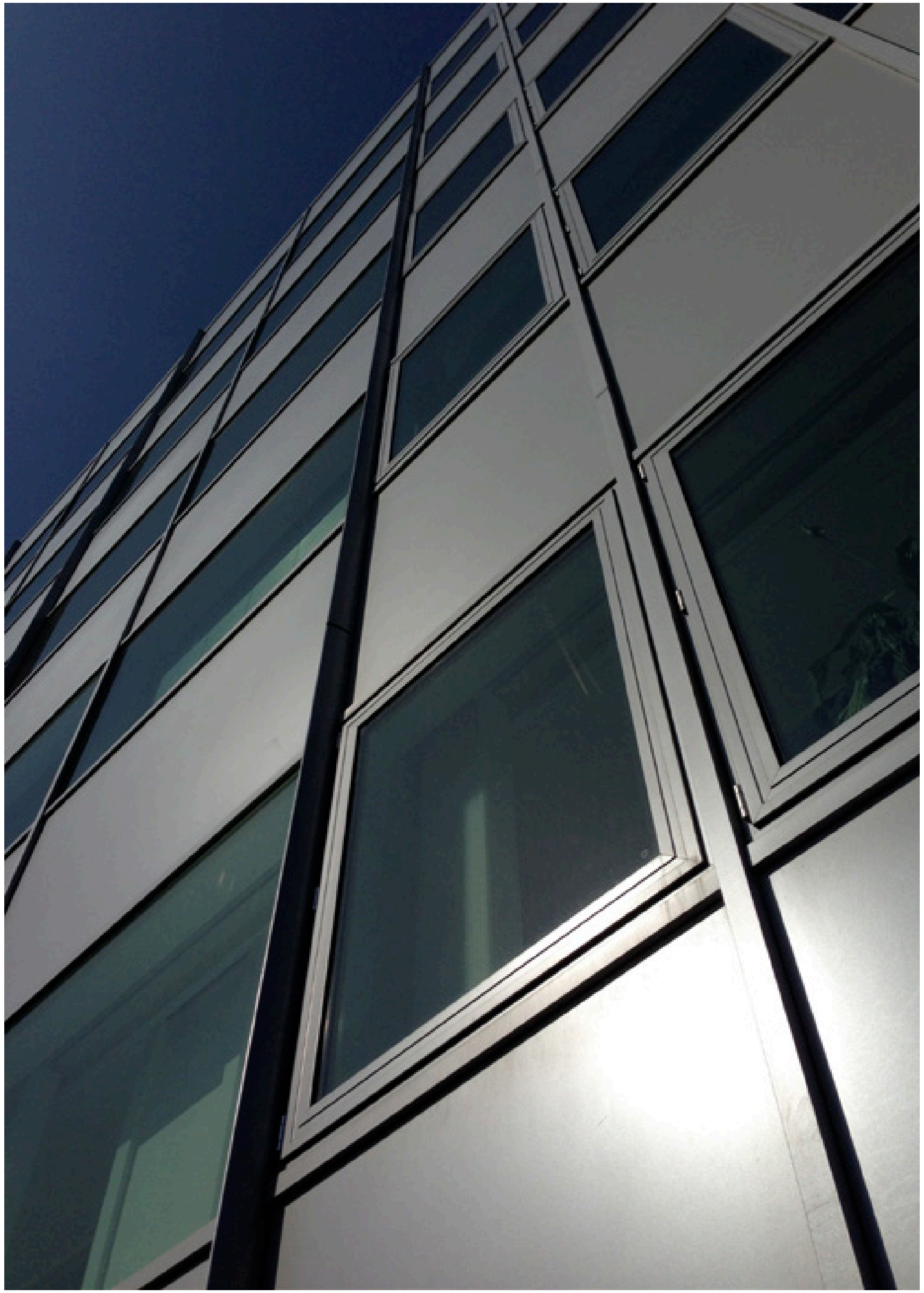
The silicone jointed curtain-walling addition is a much more recent construction, which is weathering well and exhibits no obvious latent defects in design, detailing or construction; there is no evident discolouring run-off nor any obvious failures developing.

Initial Further Research Action

A. Not considered a candidate for non-destructive testing as part of the research, because the 1973 phase of George House has been subjected to non-destructive testing by Syntha Pulvin. See Appendix B for the results of this testing.

Fig 5.17 Syntha Pulvin polyester powder-coated aluminium cladding on the rear extension

Fig 5.18 Window and panel detail of the rear extension



Herman Miller, Chippenham, Wiltshire, England: Architect Nicholas Grimshaw & Partners, 1983

Fig 5.19 Herman Miller Distribution Centre, Chippenham: light blue polyester powder-coated pressed aluminium cladding

Date of visit:	20 April 2013	
Time of visit:	11am	
Visited by:	Michael Stacey	
Location:	Chippenham, Wiltshire, England	
Year of completion:	1983	
Architect:	Nicholas Grimshaw & Partners[1]	
Owner/client:	Herman Miller	
Weather:	Sunny and dry	
Access:	Unrestricted access to the exterior only	
Materials and finish:	Polyester powder coated: pressed aluminium cladding, extruded external cladding rails and aluminium window frames. Three blues were used:	
Panels and windows:	light blue	Ral 5012
External pods:	dark blue	Ral 5010
T-bar aluminium extrusion:	cobalt blue	Ral 5003

Fig 5.20 Light blue polyester powder-coated curved corner panel aluminium cladding

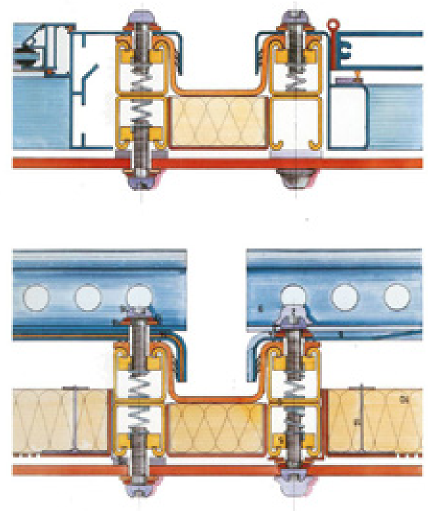


Fig 5.21 Detail by Nicholas Grimshaw & Partners showing interchangeable pressed aluminium cladding panel – a simple neoprene gasket provides weatherproofing at each vertical joint

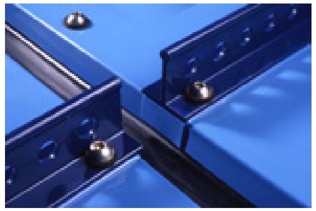


Fig 5.22 Note the expressed cobalt blue extruded cladding rails

Fig 5.23 RAL colour chart including the shades of blue used on Herman Miller Distribution Centre, Chippenham by Nicholas Grimshaw & Partners

Case Study Data

Designed by Nicholas Grimshaw with project architect Neven Sidor, and completed in 1983, this award-winning furniture distribution centre has been very successfully used by Herman Miller. The flexible and interchangeable panel system, based on a 2.4m × 1.2m grid, has proved its value in the ease with which Herman Miller has added a new roller shutter door to the eastern end of the south façade. Farrell and Grimshaw's earlier Herman Miller Factory in Bath, completed in 1977, is also clad in an interchange system of glass and beige GRP insulated panels.

For the Herman Miller Distribution Centre in Chippenham, 2mm-thick pressed aluminium panels were manufactured by Kinain Workshops and fixed by R. M. Douglas. These were polyester powder coated by Acorn Anodising, using three blue Syntha Pulvin polyester powders.

Observations

The light blue - Ral 5012 polyester powder coating on the panels and windows has faded and chalked during its 31 years in the sun, wind and weather of Wiltshire, particularly on the south façade. However, it should be noted that three blues were specified and the pods are still a darker blue than the primary cladding and this should not be mistaken for fading. The polyester powder-coated aluminium cladding of the south façade that is sheltered by the pods, which are articulated on the plan on p. 232, has remained close to the original colour, light blue - Ral 5012.

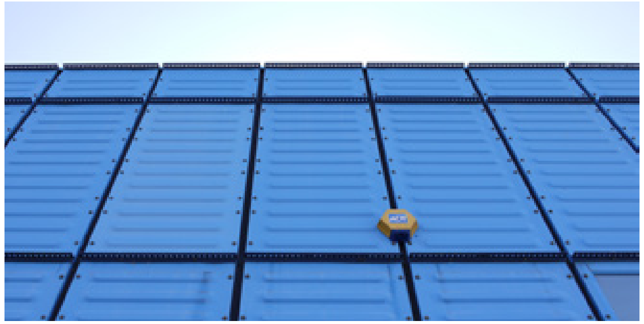


Fig 5.24 Detail of the light blue ribbed polyester powder-coated aluminium panels

Fig 5.25 The recyclability of this building fits with Herman Miller's company ethos

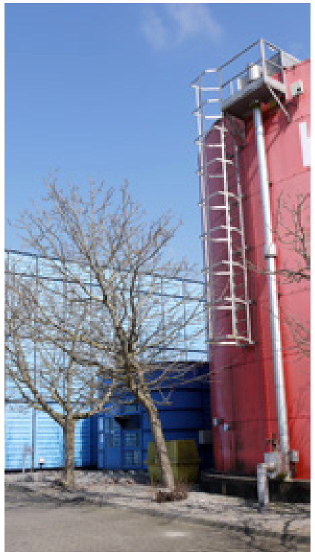


Fig 5.27 The sprinkler water storage tank and articulated pod shelters part of the south façade

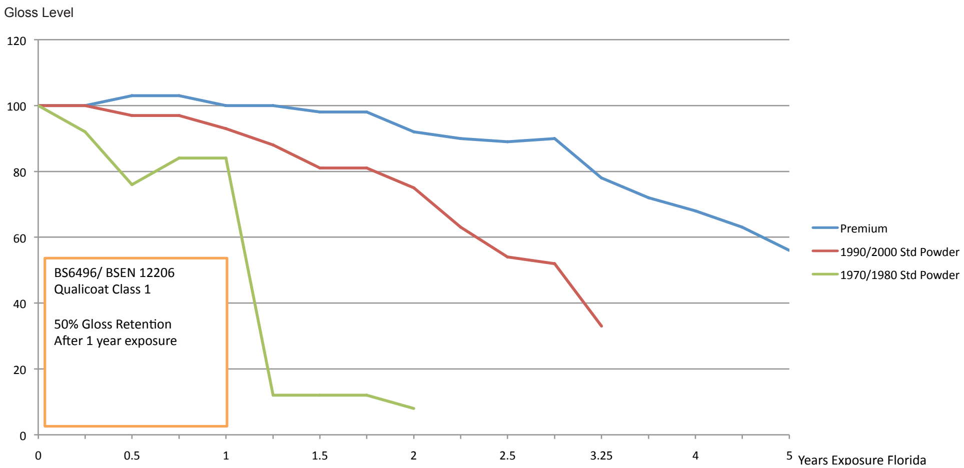


Fig 5.26 Valspar Powder Coatings: typical contemporary performance of polyester powder coatings, based on Florida high-insolation testing

Fig 5.28 A pod sheltering part of the south façade

There is no evidence of cleaning on any of the four façades. Staining and mosses were noted on the north façade. The surface fixing of the panels and the expressed perforated extruded cladding rail has exacerbated staining and dirt build-up. Around the loading bay on the west façade, some mechanical damage was noted. A Hewi nylon-coated door handle on the external door to one of the pods was significantly eroded down to its metal core. A 'store' of interchangeable panels and window frames was found beyond the south façade. These had been removed to enable a new roller shutter door to be installed – a good demonstration of the benefits of a flexible and interchangeable cladding and glazing system. The Herman Miller Duty Officer observed that the company was moving to Melksham as it had outgrown this site and required a larger distribution centre. He did not know what was to become of the building; however, he did know that 'the building could be relocated and reused or disassembled and recycled as it was made of discrete component parts'. He added that 'it would not just be demolished into rubble on-site like a traditional masonry building'.[2] Contemporary polyester powder coating is much more fade-resistant, including blues, and it takes longer for any chalking from the resin to become evident, see Figure 5.26 opposite.

Initial Further Research Actions

A. Is blue polyester powder coating still problematic?
B. Potential candidate for non-destructive testing – selected for testing, for plan and test locations, see Chapter Six.

Notes

1 The current practice name of Nicholas Grimshaw & Partners is Grimshaw Architects.
2 Recorded by Michael Stacey, 20 April 2013.

Fig 5.29 Pressing aluminium cladding panels at Kinain Workshops

Fig 5.30 The light blue polyester powder-coated aluminium cladding of the west façade has faded and chalked over the course of more than 30 years in the sun

Fig 5.31 Polyester powder-coated pressed aluminium interchangeable panels and windows of the south façade

Fig 5.32 Hewi nylon-coated door handle significantly eroded down to its metal core

Fig 5.33 Polyester powder-coated pressed aluminium: note the new shutter door

Fig 5.34 Spare interchangeable polyester powder-coated pressed aluminium panels and windows – a result of the newly installed shutter door

Fig 5.35 Detail of the light blue ribbed cladding of the south façade: note that this is almost the original blue as it has been sheltered from the sun by the pod opposite

1 Finsbury Avenue, London, England: Architect Arup Associates, Curtain Walling Josef Gartner, 1985

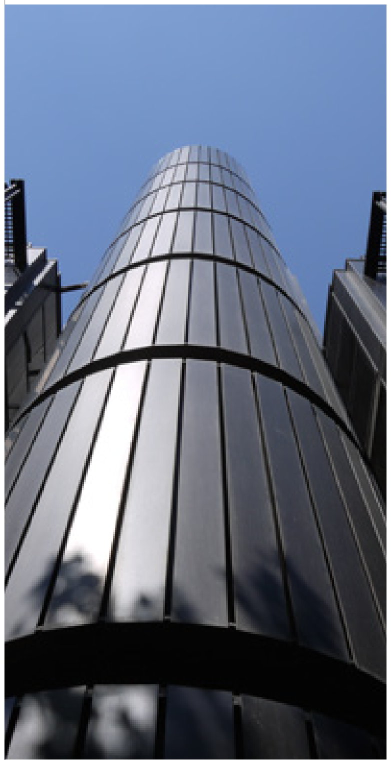


Fig 5.37 Bronze anodised extruded aluminium cladding on the stair tower of 1 Finsbury Avenue, architect Arup Associates, 1985

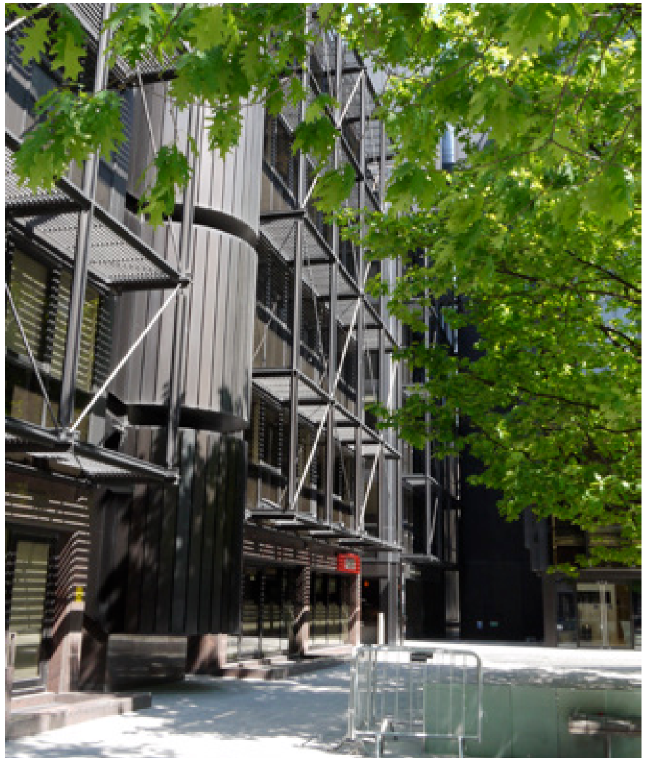


Fig 5.38 South-east façade

Date of visit:	27 May 2012
Time of visit:	11am
Visited by:	Michael Stacey
Location:	1 Finsbury Avenue, London, England
Year of completion:	1985
Architect:	Arup Associates
Owner/client:	UBS
Weather:	Sunny and dry
Access:	Unrestricted access to the exterior only (once agreed with security)
Materials and finish:	Bronze anodised aluminium extrusions forming curtain walling, cladding, brise soleil and access walkways

Fig 5.36 [left] Bronze anodised curtain walling at the entrance to 1 Finsbury Avenue

Fig 5.39 Bronze anodised curtain walling of 1 Finsbury Avenue

Case Study Data

This purpose-built office building was designed by Arup Associates and completed in 1985.[1] The sophisticated suite of aluminium extrusions, which form the curtain walling, brise soleil, access walkways and cladding, were designed and engineered by Josef Gartner of West Germany, then one of the best curtain-walling companies in the world.[2]

Observations

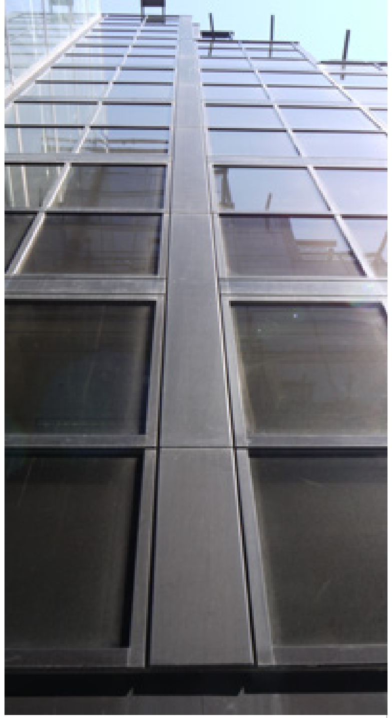
1 Finsbury Avenue now sits comfortably in a mature soft landscape within a well-considered hard landscape forming the first phase of the Broadgate 'groundscraper' development. This is a sophisticated work of architecture that reflects Arup's expertise as a multi-disciplinary practice and in the design of offices including Gateway 1 and 2. The design of the curtain-walling system with bespoke extrusions by Gartner is equally sophisticated. The bronze anodising is generally in very good condition, having weathered in a very similar manner to bronze, see the comparison with an outdoor example of a cast bronze sculpture by Henry Moore at Kew, Figure 5.44.

Fig 5.40 [right] Discolouration of the bronze anodised cladding

Fig 5.41 [below] Expressed cruciform of the bronze anodised curtain walling

Fig 5.42 [right] Detail of the bronze anodised curtain walling of 1 Finsbury Avenue, architect Arup Associates

Fig 5.43 [below] The only noticeable weathering of the curtain walling is below certain details and especially at cut ends of extruded sections



Some corrosion was noted at the cut ends of the bronze anodised sections, particularly where four sections come together. This suggests that the sections were cut after anodising. On the stair towers, some colour variation in the bronze anodising of the extruded aluminium cladding is apparent but it is within an acceptable range. There is little evidence of the curtain-walling section having ever been cleaned, despite provision of very good access.

Initial Further Research Actions

A. Potential candidate for non-destructive testing – selected for testing, for plan and test locations, see Chapter Six.

B. What is the typical colour range on bronze anodising?

Notes

1 A. Brookes and M. Stacey (1985), *Aluminium extrusions*, Architects' Journal, 20 November, pp. 152–157; A. Brookes and C. Grech (1990), *Building Envelope*, Butterworth, Oxford, pp. 41–45.

2 Ibid.

Fig 5.44 *Hill* Arches, Henry Moore, 1973, Kew Gardens, London, LH 641 Bronze, Edition of 7

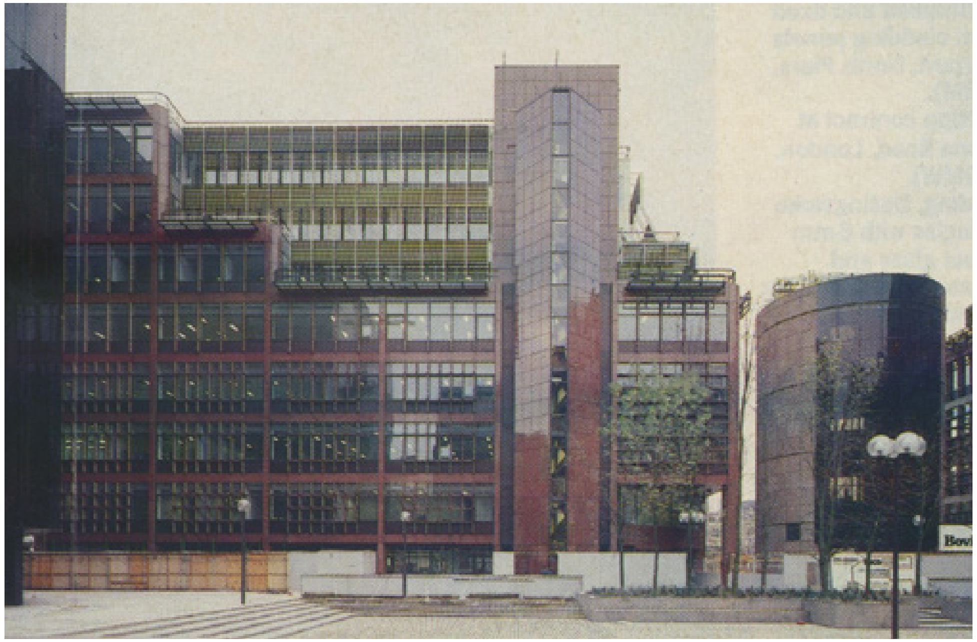


Fig 5.45 4 and 6 Broadgate, photographed October 1988

Fig 5.46 The granite-clad 4 and 6 Broadgate were demolished in 2011

Postscript to 1 Finsbury Avenue

In the immediate context of 1 Finsbury Avenue were 4 and 6 Broadgate, also designed by Arup Associates. The demolition of these buildings began in 2011, to create space for MAKE's new 'groundscraper' that is intended to consolidate all of UBS's London operations into one building. The building will house up to 6,000 staff and include four trading floors to accommodate up to 750 traders per floor. This major City of London development also includes public realm and landscaping enhancements from Sun Street Passage to Primrose Street, and the introduction of retail space in the new Sun Street Square. Prior to demolition, opposition came from groups such as the Twentieth Century Society called for the complete 1980s Broadgate Complex designed by Arup to be Grade II listed.

Fig 5.47 Construction of 5 Broadgate, November 2013

Parsons House Over-Cladding, London, England: Architect Peter Bell & Partners, 1986

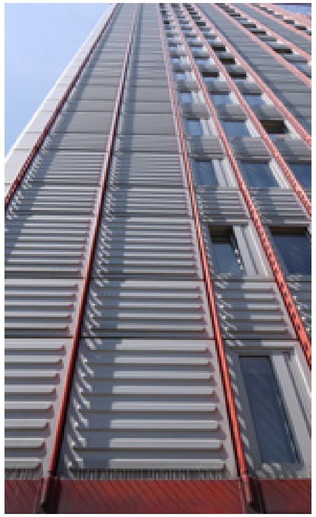


Fig 5.48 [left] Parsons House, over-cladding, architect Peter Bell & Partners

Fig 5.49 [above] Polyester powder-coated aluminium mullions, panels, louvres and windows

Date of visit:	27 May 2012
Time of visit:	3pm
Visited by:	Michael Stacey
Location:	Hall Place, London W2, England
Year of completion:	1969 and1986 (over-cladding)
Architect:	Peter Bell & Partners
Owner/client:	Westminster City Council
Weather:	Sunny and dry
Access:	Unrestricted access to the exterior only
Materials and finish:	Over-cladding using polyester powder-coated aluminium mullions, panels and windows, with tile-clad base

Fig 5.50 [right] Polyester powder-coated aluminium mullions, panels, louvres and windows of Parsons House were installed by specialist subcontractors Schmidlin

Fig 5.51 Detail of the façade of Parsons House

Case Study Data

The 21-storey tower at Hall Place, Parsons House, was built by Westminster City Council and completed in 1969. The construction quality was very poor, leading to spalling concrete and rotten timber windows in under 20 years. Construction quality in the UK in the 1960s was often poor, in part due to the haste to rehouse people after the Second World War. By 1989, four million people in the UK had been housed in new homes since the end of the war. The poor condition of Parsons House was extremely evident in the mid-1980s when, as well as spalling concrete, there was a significant risk of windows falling out. This led to the council commissioning architect Peter Bell & Partners with specialist consultant Bickerdike Allen Partners to design an over-cladding system for this tower. Peter Bell's design for the over-cladding comprises bright red polyester powder-coated aluminium mullions with pressed aluminium panels, curved aluminium corner panels, aluminium louvre panels and aluminium-framed double-glazed windows, all specified to be finished with a light grey polyester powder coating. The tower is crowned with an expressive cleaning access system, also in bright red. The over-cladding has the advantage of wrapping the building in insulation, which significantly reduces the U-values whilst insulating all of the cold bridges of the original construction. On Parsons House mineral wool 80mm thick was specified.

One logistical constraint was that the tower needed to be over-clad from the outside, with the contractor only entering the occupied flats to remove the old windows and form reveals to the new windows. The contract was won by Schmidlin, who installed a system using Coloursec to provide the bright red and light grey polyester powder coating. Although the investment in this over-cladding was significant, about £220/m^2 in 1986, it was seen as a long-term investment. Alan Brookes recorded that 'the cladding should not require repainting for 40 years'.[1] It is pertinent to note that the guarantees provided on polyester powder coating at the time were between 10 and 15 years only.

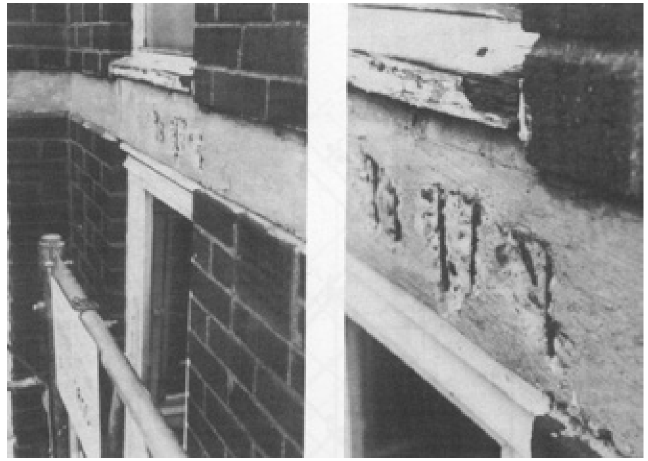


Fig 5.52 Parsons House prior to over-cladding: spalling concrete and rotten timber windows

Fig 5.53 Parsons House, completed in 1969: brick with a concrete frame and timber windows

Fig 5.54 Tiled base of Parsons House: note the anti-pigeon measures and the staining to the tiles

Fig 5.55 Polyester powder-coated aluminium window, note the filiform corrosion to the mitred corner and at drainage holes

Below is an indicative history of the development of aluminium polyester powder coating guarantees, in this case from Syntha Pulvin:

1972	Gloss products	10 years
1984	Matt products	15 years
1991	Metallic products	15 years
1994	Gloss/satin products	15 years
	Matt/metallic products	25 years
2007	Matt/metallic products	30 years
	Premium products (Qualicoat Class 2)	40 years

These guarantees are applicable to any project in the British Isles and Northern Europe (above 48° latitude) in a non-hazardous environment.[2] For a review of currently available guarantees for finishes on aluminium, see Chapter Eight.

Observations

Sited in west London, this is successful housing in a good location, in the form of a 21-storey tower of apartments. Although a cleaning access system is provided at eaves level, this appears to have been used only for window cleaning. There was no evidence that the polyester powder coated profiled aluminium components, especially the panels and mullions, have ever been cleaned. However, the polyester powder coatings are generally in good condition with only limited fading of the bright red and a general matt appearance for both colours, which in part results from the lack of cleaning. Clearly, pigeons are also a maintenance problem for this apartment tower. It is interesting to note that the ceramic tiles of the base are more discoloured by staining than the polyester powder-coated aluminium panels.

On the windows that could be readily inspected, filiform corrosion was noted at cut ends of the extruded aluminium sections and at drainage or weep holes in these sections. Clearly, the sections were fabricated after coating and this corrosion suggests the pre-treatment has been found somewhat wanting after 26 years of exposure to wind, sun and rain. In part due to the apparent lack of cleaning, this building was not shortlisted for non-destructive testing.

Initial Further Research Action

A. Unlikely to be a candidate for non-destructive testing do to access and problems of intrusion.

Notes

1 A. Brookes and C. Grech (1990), *Building Envelope*, Butterworth, Oxford, p. 80
2 Guarantee data provided by Chris Mansfield of Valspar, 18 July 2012

Cribbs Causeway, near Bristol, England: Architect Building Design Partnership, 1986

Fig 5.56 Polyester powder-coated pressed aluminium cladding of Cribbs Causeway, architect BDP

Date of visit:	20 April 2013
Time of visit:	3pm
Visited by:	Michael Stacey
Location:	Off Junction 17 of the M5, near Bristol, England
Year of completion:	1986
Architect:	Building Design Partnership [BDP] (Project Architect: Gennaro Picardi)
Owner/client:	Prudential Assurance Company (original owner)
Weather:	Sun with clouds and dry
Access:	Unrestricted access to the exterior and interior of the shops, whihc are currently trading
Materials and finish:	Coloursec silver metallic polyester powder coating on the pressed aluminium panels and SlimWall curtain with sidewalls of silver PVDF coil-coated galvanised steel sheets, Architectural Profiles (AP 22 profile). Note eves and rainwater goods were originally pale yellow – now all painted white

Fig 5.57 Some retail units were empty when the project was inspected

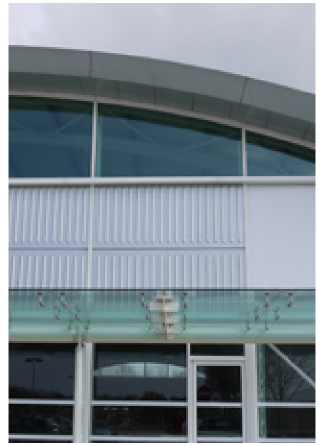


Fig 5.58 Detail of a retail façade

Fig 5.59 Rear loading bay façade: polyester powder-coated pressed aluminium

Fig 5.60 Side façade of silver PVDF coil-coated steel sheeting, showing no sign of corrosion

Fig 5.61 A new advertising sign at Cribbs Causeway

Fig 5.62 Corrosion at the seam detail of the silver PVDF coil-coated steel sheeting

Fig 5.63 Front façade

Case Study Data

Cribbs Causeway was designed by BDP and the Project Architect was Gennaro Picardi.[1] The curtain walling, with interchangeable glazing and pressed aluminium panels, was fabricated and installed by Schmidlin.

Observations

Cribbs Causeway is a retail park, an early example of an out-of-town shopping centre, designed by BDP in the form of two adjacent blocks looking onto a car park. Reflecting the post-2008 recession, some units are empty. Pressed aluminium panels are generally in good order, with some mechanical damage noted from the inside, which is unusual. Overall, the look of the retail park is significantly altered with new(ish) signage and signage structures.

PC World has over-painted the silver pressed aluminium paints with white paint, for reasons of corporate identity. However, 'ordinary' paint has been used and peeling was noted. PC World side cladding should be either over-clad or replaced with flat panels.

The rear façade of Building B (southern building) is the least altered and closest to the original published photographs.[2] As regards the profiled steel sheeting, poor workmanship and corrosion were noted. This was the only corrosion observed on any of the 12 visits and this steel sheeting was only 27 years old at the time of inspection.

Initial Further Research Actions

A. What is the best practice for over-painting PPC or PVDF if a corporate change of identify is required? According to current best practice, if it is necessary to change the colour of a polyester powder-coated facade, it is practical to specify a wet-applied PVDF paint system and companies such as Tomburn will provide a ten-year guarantee for such a finish. This includes a dent repair service, if required.

Notes

1 A. Brookes and C. Grech (1990), *Building Envelope*, Butterworth, Oxford, pp. 27-30
2 Ibid

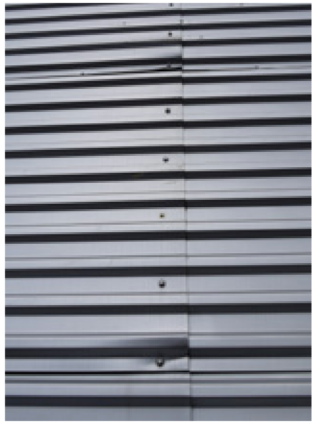


Fig 5.64 Silver PVDF coil-coated steel sheeting of Cribbs Causeway, note poor original workmanship remains dissatisfactory for the life of a building, unless remedial work is undertaken

Fig 5.65 Polyester powder-coated pressed aluminium and composite panels

Fig 5.66 The original two blocks of Cribbs Causeway provide retail space of 7,000m^2 and 9,000 m^2 respectively. Building A is four 21m bays wide and four 21m bays deep and Building B is six 18m bays wide and seven 12m bays deep

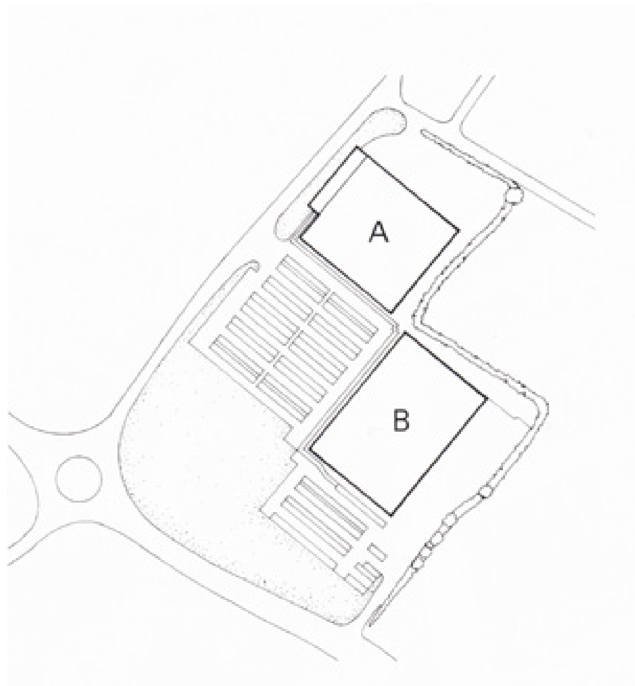


Fig 5.67 Cribbs Causeway Building B Front elevation: polyester powder-coated pressed aluminium panels in a curtain-walling system

Fig 5.68 Cribbs Causeway Building A side elevation: detail of the composite panels

Fig 5.69 Peeling over-painted polyester powder coating found at Cribbs Causeway Building A

Fig 5.70 St James' Park, Newcastle, clad in Aspect 3, integrated composite metal panel system – invented, designed, developed and tested by Michael Stacey

Financial Times Printworks, London, England: Architect Grimshaw Architects, 1988

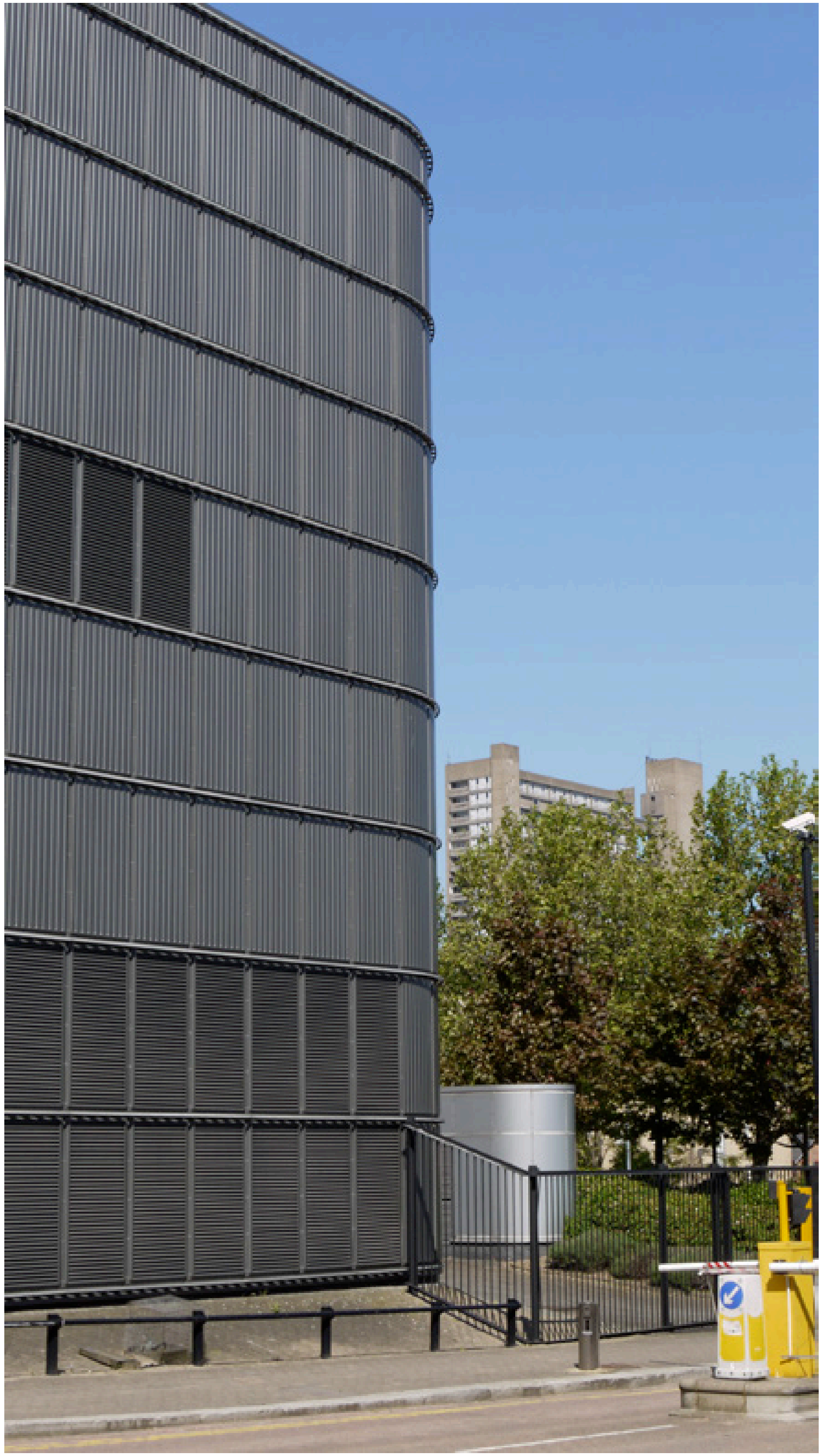


Fig 5.71 [left] PVDF-coated aluminium cladding with silver anodised cladding rails of the Financial Times Printworks, architect Nicholas Grimshaw & Partners

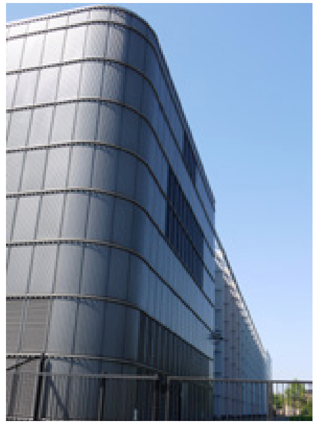


Fig 5.72 Curved corner panels and cladding rails of the Financial Times Printworks, London

Fig 5.73 Façade detail of the Financial Times Printworks

Date of visit:	27 May 2012
Time of visit:	10am
Visited by:	Michael Stacey
Location:	Off the A13 near Canary Wharf, London, England
Year of completion:	1988
Architect:	Nicholas Grimshaw & Partners[1]
Owner/client:	Global Switch
Weather:	Sunny and dry
Access:	Unrestricted access to the exterior only
Materials and finish:	PVDF-coated aluminium cladding panels with silver-anodised extruded aluminium cladding rails

Case Study Data

This purposed industrial building, off the A13 near Canary Wharf, was designed by Nicholas Grimshaw & Partners and completed in 1988.[2] The former Financial Times Printworks is an award-winning example of 'high-tech' architecture that has outlived its original economic purpose.[3]

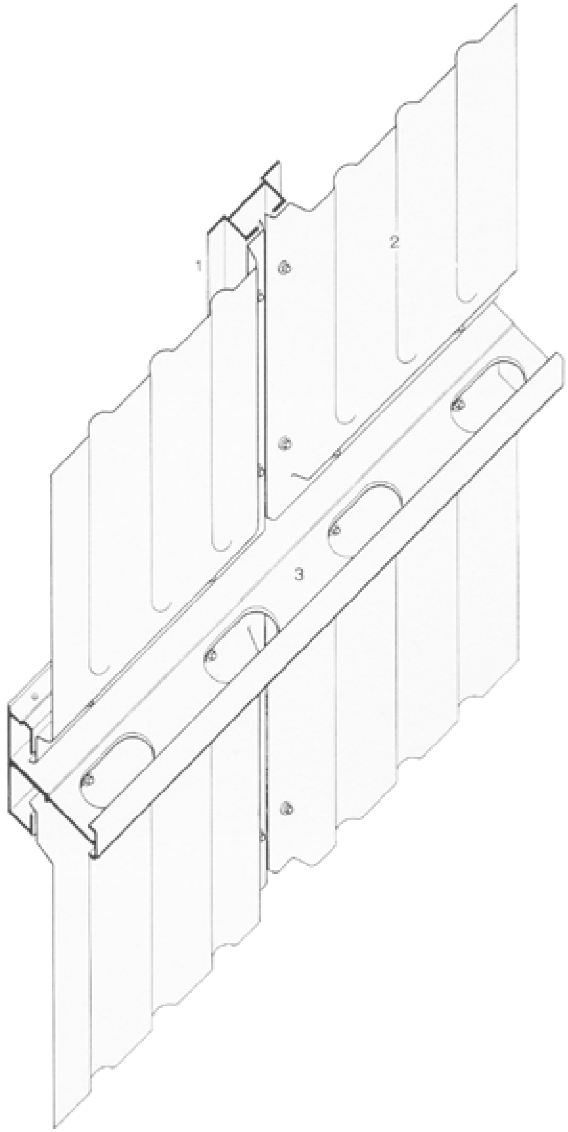


Fig 5.74 Cut-away axonometric of cladding assembly of the Financial Times Printworks: **1** vertical extruded aluminium cladding rail; **2** vacuum-formed aluminium panels; **3** horizontal extruded aluminium channel with projecting cladding rail

Fig 5.75 Detail of cladding rail and pressed aluminium panels

Observations

Built to house the printworks of the Financial Times, this building has closely mapped technological change over the past 25 years, and is now used as a data centre by Global Switch. The Duranar PVDF-coated superplastic aluminium cladding looks as new, with only mechanical damage near larger doorways showing any sign of age. Similarly the silver- or 'natural'-anodised extruded aluminium cladding rails appear 'ageless'. In comparison, the steel columns supporting the diaphanous screen of toughened glass were painted on site and have faded to a range of colours, with some columns appearing to be incongruously pink in colour.

Initial Further Research Actions

A. Good candidate for non-destructive testing.

Notes

1 The current practice name of Nicholas Grimshaw & Partners is Grimshaw Architects.
2 M. Stacey (1988), *Maximum Vision*, AJ Focus, October, pp. 14-15; A. Brookes and M. Stacey (1990), *Cladding Product Review*, AJ Focus, March, pp. 25–42; A. Brookes and C. Grech (1992), *Connections*, Butterworth, Oxford, pp. 42–45.
3 Ibid.

Fig. 5.76 Financial Times Printworks under construction in 1988, courtesy of Baco Contracts Ltd

Fig 5.77 Original construction photograph of the curved corner panels and rails, courtesy of Baco Contracts Ltd

Fig 5.78 [next pages] Financial Times Printworks under construction, courtesy of Baco Contracts Ltd


BA

Lutyens' House, London, England: Architect Sir Edwin Lutyens, 1925; New Rear Façade Brookes & Stacey, 1989

Fig 5.80 New rear façade of Lutyens' House, polyester powder-coated unitised curtain walling, designed by Brookes & Stacey

Fig 5.79 [left] Lutyens' House, architect Sir Edward Lutyens, 1925, front façade is composed of Portland stone and steel windows

Date of visit:	27 May 2012
Time of visit:	10am
Visited by:	Michael Stacey
Location:	1 Finsbury Circus, London, England
Year of completion:	1925, new rear façade 1989
Architect:	Sir Edwin Lutyens, new rear façade Brookes & Stacey
Owner/client:	Cisco
Weather:	Sunny and dry
Access:	Restricted access to the exterior only
Materials and finish:	Polyester powder-coated curtain walling and rainscreen cladding panels

Case Study Data

Lutyens' House at 1 Finsbury Circus, designed by Sir Edwin Lutyens and now Grade I listed, was completed in 1925. During the late 1980s, it underwent total refurbishment with only the front façade and principal internal features being retained. The offices had to be uprated to accommodate the services needed for computer based-office work. The demolition of the glazed brick rear façade also achieved a higher gross-to-net ratio and more lettable and useable office space.

The rear façades required a proportion system that would gain the approval of English Heritage, whilst also achieving fast-track construction with a fire-rated curtain-walling system for the central zone (indicated by the black mullions and smaller glazing format). This combination of performance characteristics was achieved by the use of a unitised polyester powder-coated aluminium curtain-walling system by Contano-Nipp to which was applied a 3mm-thick aluminium polyester powder-coated rainscreen cladding. A guarantee period of 20 years was specified for this finish and Brookes & Stacey observed that the rainscreen cladding 'has the advantage of allowing the panels to be unclipped later and returned to the factory for reapplication of the polyester powder coating'.[1] Twenty-three years later, at the time of inspection, this has not proved necessary but remains a possibility.

Observations

Although a cradle access system was included before this became a requirement of CDM Regulations, introduced in 1994, there was little evidence of cleaning despite this being a requirement of the guarantee on the polyester powder coating. However, as stated above, the panels have not needed to be recoated. It is interesting to note that unitised curtain walling was still seen as radical in the UK in the late 1980s. It is now the norm for curtain walling on tight urban sites.

Initial Further Research Actions

A. Good candidate for non-destructive testing, except for apparent lack of cleaning.

Note

1 A. Brookes and M. Stacey (1988), *Curtain Walling Product Review*, AJ Focus, October, p. 37

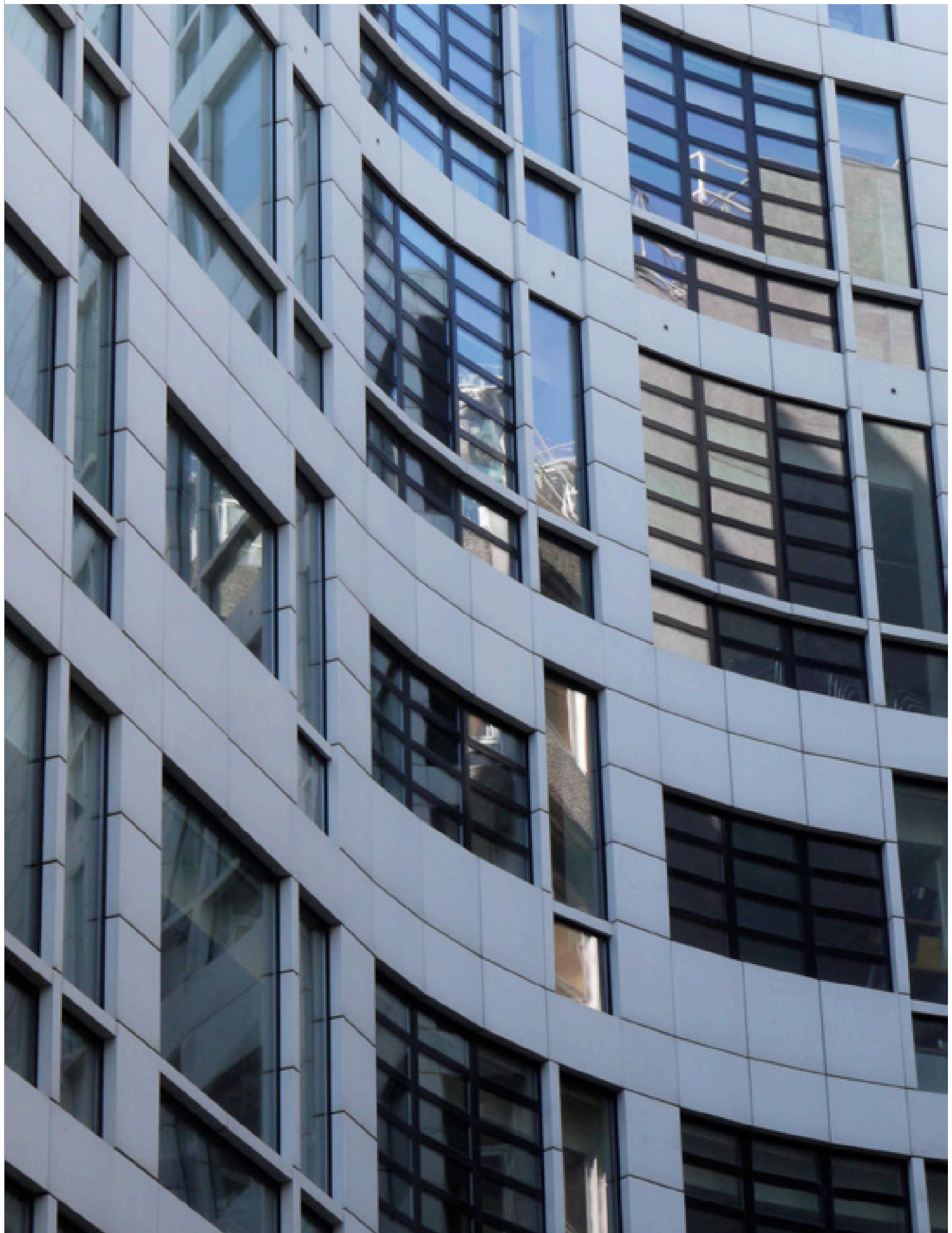


Fig 5.81 Rear façade of Lutyens' House by Brookes & Stacey, 1989, polyester powder-coated, unitised aluminium curtain walling

Imperium, Reading, Berkshire, England: Architect Bennetts Associates, 1989

Fig 5.82 Imperium, Reading, architect Bennetts Associates: polyester powder-coated aluminium curtain walling and panels

Date of visit:	5 May 2013
Time of visit:	9am
Visited by:	Toby Blackman
Location:	Reading, Berkshire, England
Year of completion:	1989
Architect:	Bennetts Associates
Owner/client:	M&G Real Estate
Weather:	Sunny and dry
Access:	Unrestricted access to the exterior only
Materials and finish:	Polyester powder-coated aluminium curtain walling and panels

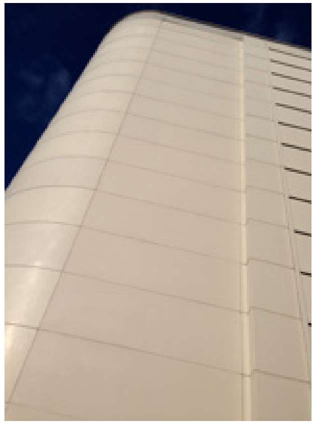


Fig 5.83 Polyester powder-coated aluminium stair tower cladding

Fig 5.84 Curved aluminium stair tower cladding

Fig 5.85 Detail of the entrance corner of the curtain walling

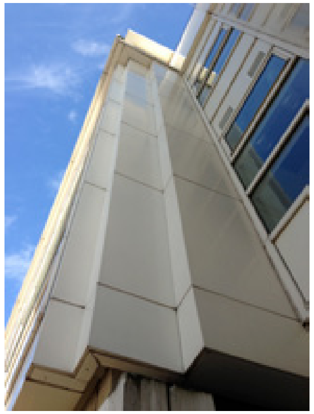


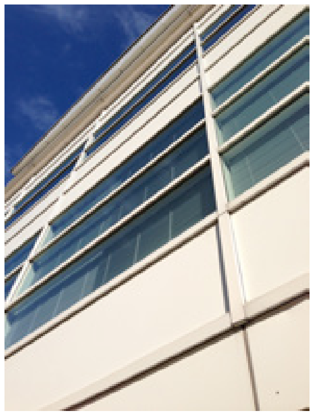
Fig 5.86 Polyester powder-coated aluminium corner panels

Fig 5.87 Polyester powder-coated entrance curtain walling

Case Study Data

Bennetts Associates were commissioned as architects for this project late in 1987, shortly after Nicholas Ridley's relaxation of planning controls allowing commercial development within areas previously designated as industrial. The design and construction team comprised Bennetts Associates (Architect), Franks & Lewin (Structural Engineer), Roger Cuthbert Associates (Services Engineer) and Tellings Ltd (Main Contractor). The building was intended for a single occupier, with flexibility for each floor to be sub-divided into four separate tenancies; therefore, air conditioning is distributed from four independent roof-level plant rooms. Imperium sits on a ground-level car park plinth, and comprises two parallel wings of deep-plan office space over three floors, with an atrium. The long-span structure was achieved with relatively shallow beams, integrated with the air-conditioning ductwork. Imperium synthesises space, structure and services in a simple overall design.

Fig 5.88 Detail of the curtain walling



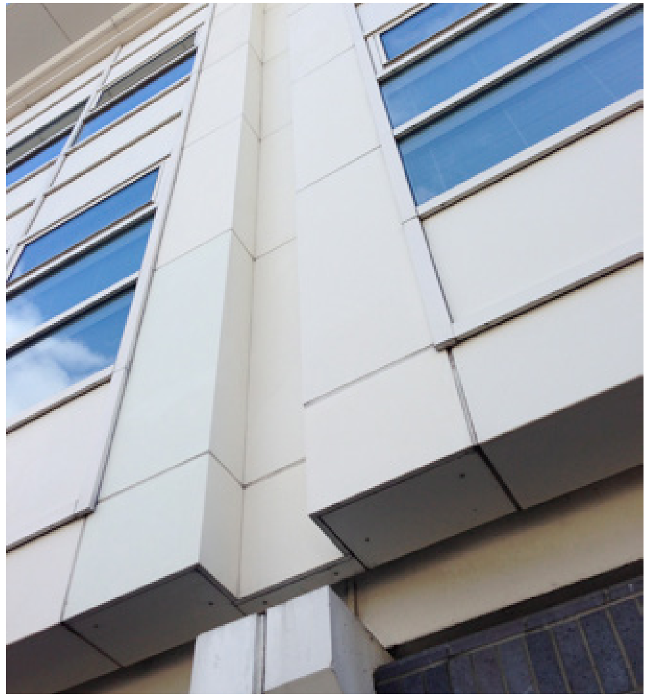


Fig 5.89 Façade detail

The building envelope was assembled from polyester powder-coated aluminium systems throughout: curtain walling, capped-stick systems in a modular form, expansion-jointed cassette panels to the circulation towers and curtain walling to the entrance lobby. The building underwent an extensive refurbishment in 2008, including internal reorganisation and renovation of the external envelope cladding.

Observations

The envelope is in remarkably good condition; the powder-coated aluminium cladding has an even, consistent finish and a high level of gloss retention. Imperium is well detailed by the architects and the assembly was well executed. This building is evidently well maintained, and there is little if any evidence of discolouring run-off, water staining or significant cladding failure.

Initial Further Research Actions

A. Potential candidate for non-destructive testing.

Camden Lock Housing, Camden, London, England: Architect Grimshaw Architects, 1990

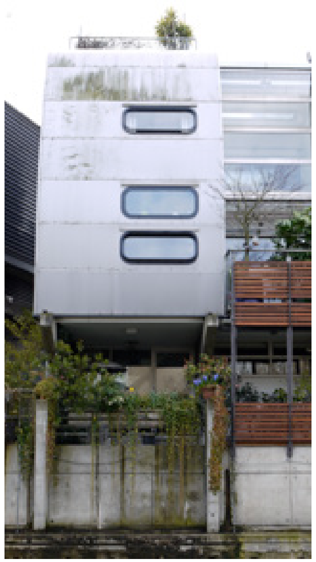


Fig 5.90 Camden Lock Housing, architect Nicholas Grimshaw & Partners, PVDF coil-coated aluminium on an end-of-terrace home

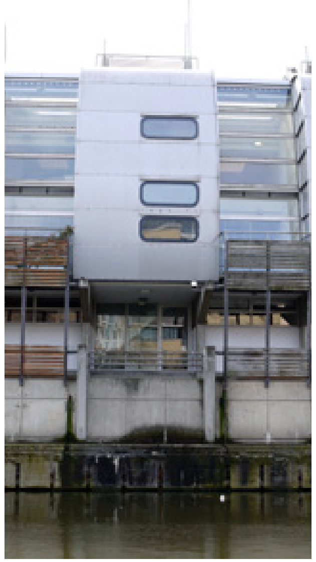


Fig 5.91 Mid-terrace home

Fig 5.92 Another mid-terrace home

Date of visit:	14 April 2013
Time of visit:	12noon
Visited by:	Michael Stacey
Location:	Camden, London, England
Year of completion:	1990
Architect:	Nicholas Grimshaw & Partners[1]
Owner/client:	Diverse private home owners
Weather:	Sunny and dry
Access:	Unrestricted access to the exterior only from the tow path on the opposite side of the Grand Union Canal (Regents Canal section)
Materials and finish:	3mm silver coil-coated PVDF aluminium

Fig 5.93 Overall view of the terrace on the Grand Union Canal

Case Study Data

This housing was designed by Nicholas Grimshaw with project architect Neven Sidor, the same team as Herman Miller Distribution Centre in Chippenham. It was a planning gain from the related Sainsbury's mixed-use development, also designed by Nicholas Grimshaw & Partners and completed in 1990.[2] The supermarket and other elements of this mixed-use urban development are clad in polyester powder-coated pressed aluminium panels.

Observations

This private housing appears to be very successful in terms of inhabitation. This north-facing canal-side elevation of silver PVDF coil-coated flat aluminium sheet, which was curved in situ to achieve the sectional profile of the houses, appears to have never been cleaned. No means of access is provided. The surface fixings and surface-fixed windows add to the streaking. Lichen build-up was noted, especially on the most sheltered house, in the micro climate of this north-facing canal-side housing. The aluminium sheeting is faring better or as well as the exposed concrete. Note that the point of contraflection of the curve of the aluminium façade profile causes staining, probably as the rate of flow of rainwater varies at this point. Electricity cables from windows to the popular roof terraces were noted on a number of the properties. The properties' market value is high.

Initial Further Research Actions

A. Not suitable for non destructive testing as access is difficult as the north-facing façades overhang the Grand Union Canal.
B. Does anyone clean their aluminium cladding and glazing sections?

Notes

1 The current practice name of Nicholas Grimshaw & Partners is Grimshaw Architects
2 A. Brookes and M. Stacey (1990), *Cladding Product Review*, AJ Focus, March, pp. 25–42

Fig 5.94 Camden Lock Housing, Grand Union Canal elevation: PVDF coil-coated aluminium

Fig 5.95 **Camden Lock Housing, PVDF coil-coated aluminium above an in-situ concrete base**

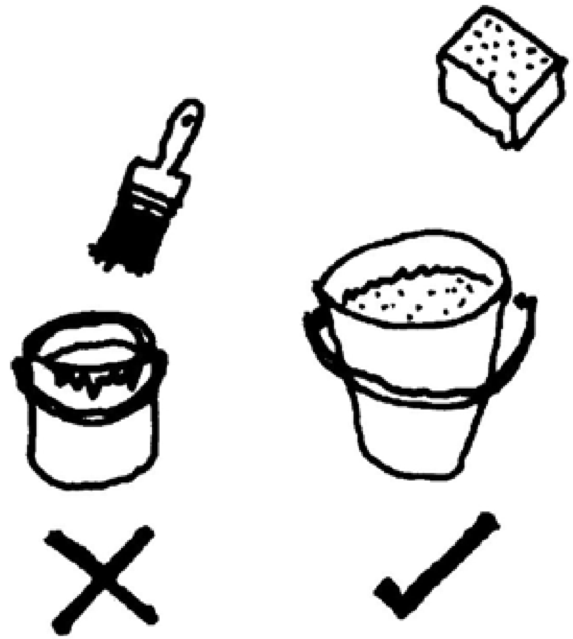


Fig 5.96 Cleaning is better than repainting, especially for aluminium finishes

Principles Underlying Durability in Aluminium in Architecture

The following are the key principles underlying durability in aluminium in architecture arising from the 12 case studies considered in this chapter and the related literature review of the TSC research programme:

- Carefully considered the detailing of the architecture. This includes the:
  - integration of the overall form and the details - the details are part of the overall architecture;
  - dimensional coordination to avoid cut ends and make-up pieces;
  - specification of a fully weather-tested system, which is not dependent on mastic and caulking.
- Good workmanship in manufacture, fabrication and assembly on site.
- Specification of a well-tested finish with good quality control procedures including random off project testing, such as that undertaken by Qualicoat.
- When specifying polyester powder coating the quality of the pre-treatment is critical. This becomes evident after many years at cut ends and cut-outs.
- Anodise sections after fabrication when possible, allowing for tong marks.
- Panels perform better than windows over time, as they typically have no cut edges.
- Detail to avoid or minimise the risk of mechanical damage; this may be how the hard landscape is detailed, not the façade.
- Interchangeable systems of panels, windows and doors offer clear advantages to all parties: manufacturers, installers, contractors and vitally the building owner and end-user.
- Details should facilitate the washing of components by rainwater. This is effectively the opposite of masonry details.
- Access for cleaning and maintenance should be built in; this is now a requirement under CDM Regulations in the UK. Access systems were noted on a number of the case studies dating back to 1968. However, there was little evidence of cleaning by building owners/occupiers.

- Detailing can facilitate the cleaning of surfaces and rainscreen panels can be detailed to avoid streaking at window cills and other details by tipping surfaces into the cavity behind the rainscreen and draining within the cavity.
- Consider the form of the proposed architecture in terms of potential staining.
- Avoid surface fixings when the budget allows, as dirt builds up on them.
- Expressed cladding rails, very popular with Nicholas Grimshaw & Partners, offer advantages in workmanship as they disguise issues of alignment and flatness of panels. However, if not regularly cleaned, these expressed details cause dirt build-up.
- Avoid crevices by providing a wider gap as in rainscreen cladding or seal with a gasket or silicone seal.
- Consider the microclimate of the site. Clearly, the Camden Lock housing by Nicholas Grimshaw & Partners has lichen build-up, as it is canal-side housing. The aluminium sheeting is faring better or as well as the exposed concrete below.

SIX

non-destructive testing

Non-Destructive Testing

From the 12 case study projects, four, all older than 25 years, were identified for non-destructive testing (with one as a back-up project) by an independent testing house. It was decided to use an independent testing house to ensure that the testing was authoritative and undertaken to international standards. Independent testing house Exova were selected to undertake this testing, which has been carried out on three projects: the New Bodleian Library, Oxford; Herman Miller Distribution Centre, Chippenham; and 1 Finsbury Avenue, London. The test methodology is included in this chapter, enabling comparative testing of aluminium-based architecture that is older than 25 years

No.	Project	Architect	Date	Current Client	Location	Aluminium Finish	Condition	Test[s] Undertaken
1	**New Bodleian Library**	Sir Giles Gilbert Scott	**1940**	University of Oxford	Oxford, England	Silver anodised	Anodised aluminium windows in excellent condition, library being refurbished by WilkinsonEyre	Coating thickness
2	**Herman Miller Distribution Center**	Nicholas Grimshaw & Partners	**1983**	Herman Miller	Chippenham, England	Syntha Pulvin Polyester powder coated	Very good condition in view of its age **–** minimal filiform corrosion on some panels (East façade only)	Coating thickness Colour Specular gloss
3	**1 Finsbury Avenue**	Arup Associates	**1985**	UBS	London, England	Bronze anodised	Very good condition, however, some apparent end corrosion observed	Coating thickness Colour
4	**Financial Times Printworks**	Nicholas Grimshaw & Partners	**1988**	Global Switch	London, England	PVDF and silver anodised extruded aluminium cladding rails	Very good – condition only very limited mechanical damage	Not tested

anywhere in the world. This non-destructive testing is explained and illustrated and the Exova report has been provided in full in Appendix A. The testing was undertaken by Geoff Addicott on behalf of Exova.

Following the inspection of the anodised aluminium cladding of the 30-storey Alcoa Building in Pittsburgh, see pages 61–63, this building, designed by Harrison & Abramovitz and completed in 1953, has been proposed as the first project to be tested as follow-up to this research.

The key for the colour differences shown in the summary test results is as follows:

L	A	B	E
+ = Lighter	+ = Redder	+ = Yellower	Indicates how much the colour deviates from standard
- = Darker	- = Greener	- = Bluer	

The Delta E value is calculated using the following equation:

$$\Delta E = \sqrt{L^2 + A^2 + B^2}$$

Proposed Methodology for Non-Destructive Testing of Aluminium Finishes on Projects over 25 Years Old

1. Overall

1.1 Gain permission to undertake the non-destructive testing of the aluminium on 3–4 projects.

1.2 Undertake a detailed photographic survey, making field notes including weather conditions.

1.3 Wash aluminium finishes with warm soapy water prior to all tests to remove any build-up of dirt or chalking.

2. For the testing of anodised aluminium, undertake the following tests:

2.1 Visually examine to determine the substrate quality and the quality of the anodic film.

2.2 Measure the coating thickness with a DFT meter.

2.3 Assess the colour with the human eye.

2.4 Use a spectrometer to measure colour, if coloured. (For silver anodising, omit Test 2.4, as it is self-coloured.)

3. For the testing of polyester powder-coated aluminium, undertake the following tests:

3.1 Measure the coating thickness with a DFT meter (dry film thickness).

3.2 Measure the specular gloss at 60° with a gloss meter.[1]

3.3 Assess the colour with the human eye.

3.4 Use a spectrometer to measure colour.

Physical testing of polyester powder coating is not possible in this context as all tests are destructive. It should be noted that the key aspect of these tests is the quality of the pre-treatment.[2]

4. Proposed sample size for testing both anodising and polyester powder coating

4.1 Only accessible samples will be tested from the outside using stepladders or ladders (noting the requirement for ladder safety training).

4.2 As it is impossible to identify batches of finished components on projects that are over 25 years old, the Towards Sustainable Cities Research Team recommends a sample size of 20 components. This is equivalent to a batch size of 91–150 in accordance with BS 3987, BS 6001, BS EN12206 and ISO 2859.

4.3 In our opinion, this will give a good indication of the durability of a representative sample of the finishes.

Notes

1 The measurement of specular gloss of non-metallic paint films is based on the principles of BS EN ISO 2813 Paints and Varnishes. Following this standard, a 60° angle was chosen as it is appropriate for most anodised and polyester powder-coated finishes. Consult this standard for the measurement angle appropriate for high gloss and matt applications.

2 At Herman Miller Distribution Centre, destructive testing may be possible on façade components that have been removed to install the roller shutter door. This may be possible on other projects during refurbishment, for example. For any polyester powder coated (PPC) project, establish with the building owner whether destructive testing of the PPC is possible.

New Bodleian Library, Oxford, England: Architect Sir Giles Gilbert Scott, 1940

Date of testing:	7 November 2013
Time of testing:	9.30am
Tested by:	Geoff Addicott, assisted by Michael Stacey and Ben Stanforth
Location:	Broad Street, Oxford, England
Year of completion:	1940
Architect:	Sir Giles Gilbert Scott
Owner/client:	University of Oxford
Weather:	Sunny and dry
Access:	Access throughout, guided by John O'Connor, MACE Group
Materials and finish:	Silver anodised aluminium windows

Using a DFT meter, coating thickness was tested, on the anodised aluminium windows of the New Bodleian Library, with a sample of 11 test windows, from all four elevations, with ten tests per window. An internal test was also conducted to compare the external tests with a more protected anodised surface. A summary of findings is presented on pages 234–236 and in full within Appendix A.

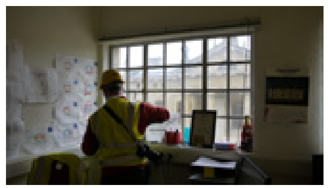
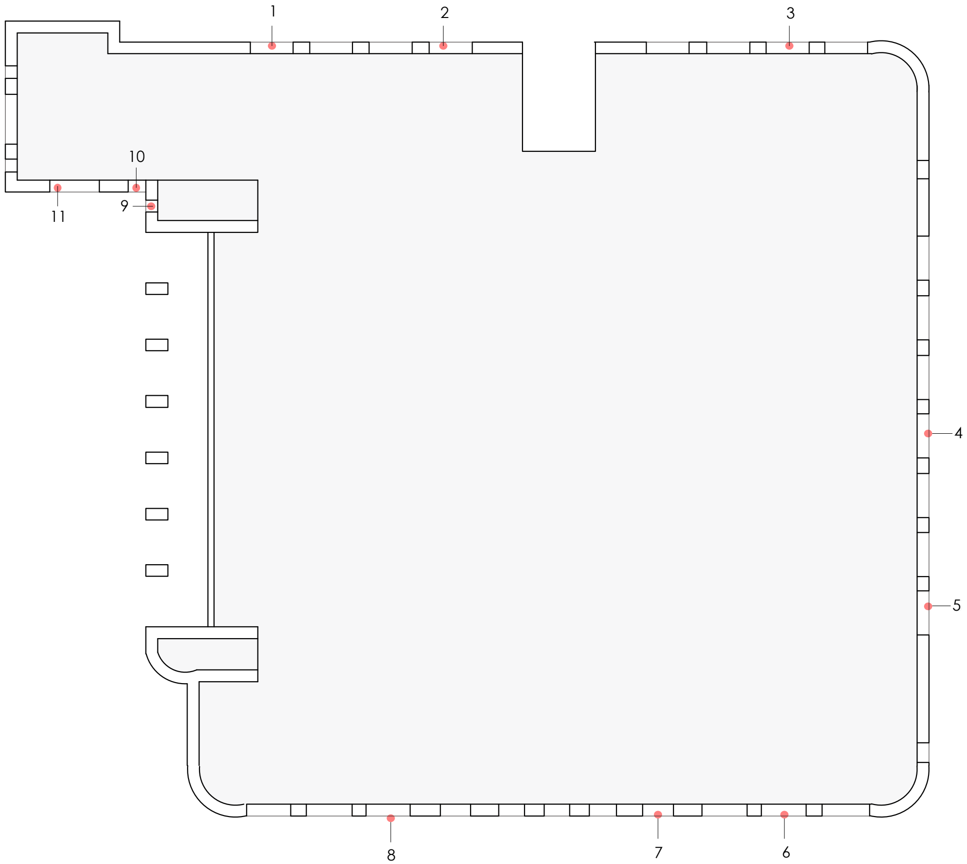


Fig 6.1 Undertaking testing at the New Bodleian Library, Oxford



12 – Internal reference window on the top floor of the south west elevation

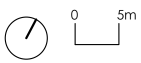


Fig 6.2 Plan of New Bodleian Library indicating the twelve sites which were tested

6.0 **CONSOLIDATED TEST RESULTS – New Bodleian Library**

6.1. The windows had the residual FT checked. The first window checked on the exterior has been used as the standard.

① 1st Window - Exterior (STD)

Max	30.0
Min	20.6
Average	25.4
SD	3.21

②

Max	24.8
Min	9.2
Average	15.3
SD	4.38

③

Max	21.6
Min	8.0
Average	14.8
SD	4.99

④

Max	18.9
Min	10.9
Average	13.6
SD	2.48

⑤

Max	22.0
Min	11.9
Average	15.5
SD	3.30

⑥

Max	17.0
Min	7.1
Average	10.7
SD	2.75

⑦

Max	18.3
Min	7.6
Average	12.1
SD	3.77

⑧

Max	15.5
Min	10.6
Average	13.4
SD	1.51

⑨

Max	13.8
Min	8.4
Average	11.7
SD	1.58

⑩

Max	19.6
Min	8.4
Average	15.3
SD	3.07

⑪

Max	18.3
Min	7.4
Average	12.9
SD	3.44

⑫ Window inside - Top floors - Site Office

Max	16.5
Min	11.0
Average	14.8
SD	1.72

Commentary on Test Results: New Bodleian Library

It is important to remember that these anodised aluminium windows of the New Bodleian Library, designed by Sir Giles Gilbert Scott, were almost 75 years old when inspected and tested.

Windows from all four elevations were tested – 12 in total. Silver anodising was found to be present and the range of film thickness was very wide from 30μm to 7.4μm. Even on the internal side of the reference window, the anodising ranged from 16.5μm to 11μm; arguably, this is representative of the range of anodising thickness achieved in the 1930s. When James Gibbons of Wolverhampton organised the anodising of these windows, it was a new technology that had only been established in the previous decade of the twentieth century.

The anodising on all except one of the aluminium windows of the New Bodleian Library would not pass the coating thickness standard required by BS EN ISO 7599:2010. The expenditure on the overall refurbishment of this library was over £50 million; based on the durability of anodised aluminium, the design team decided that the anodised finish is satisfactory for another 60 years or more. The windows were only cleaned and reglazed.

Architect WilkinsonEyre's project statement observes of the New Bodleian Library that: 'The existing building is in one of the most historically sensitive parts of the city, and is part of a series of buildings forming one of the most memorable urban "set pieces" in the United Kingdom.'[1] When the library reopened to academics in the autumn of 2014, it was renamed the Weston Library.

Note

1 WilkinsonEyre (2010), *New Bodleian Library: Architect's Statement*, 26 February, available online at www.bodleian.ox.ac.uk/__data/assets/pdf_file/0004/65884/Wilkinson-Eyre-Architects-Architects-statement.pdf (accessed September 2013).

Herman Miller Distribution Centre, Chippenham, Wiltshire, England: Architect Nicholas Grimshaw & Partners, 1983

Date of testing:	15 October 2013
Time of testing:	9am
Tested by:	Geoff Addicott, assisted by Ben Stanforth
Location:	Chippenham, Wiltshire, England
Year of completion:	1983
Architect:	Nicholas Grimshaw & Partners
Owner/client:	Herman Miller
Weather:	Sunny and dry
Access:	Unrestricted access to the exterior only
Materials and finish:	Polyester powder-coated in three blues: pressed aluminium cladding, extruded external cladding rails and aluminium window frames

Three tests were conducted at a sample of 13 test sites, including all four façades of the building. The four pods were also included in the test as well as areas protected from wind, sun and rain. Coating thickness, colour and specular gloss were tested using a DFT meter, an X-Rite meter and a gloss meter. A summary of results is presented on pages 240–245 and in full in Appendix A. It should be noted that filiform corrosion was found on the sheltered east façade. Filiform corrosion is a thread-like form of corrosion that occurs under organic coatings including polyester powder coating. The source of infiltration is often a defect or mechanical scratch in the coating. Filiform corrosion is a superficial attack of the surface and typically only a visual problem.

Fig 6.3 DFT meter used to measure coating thickness and X-Rite colour meter

Fig 6.4 Undertaking testing at Herman Miller, Chippenham

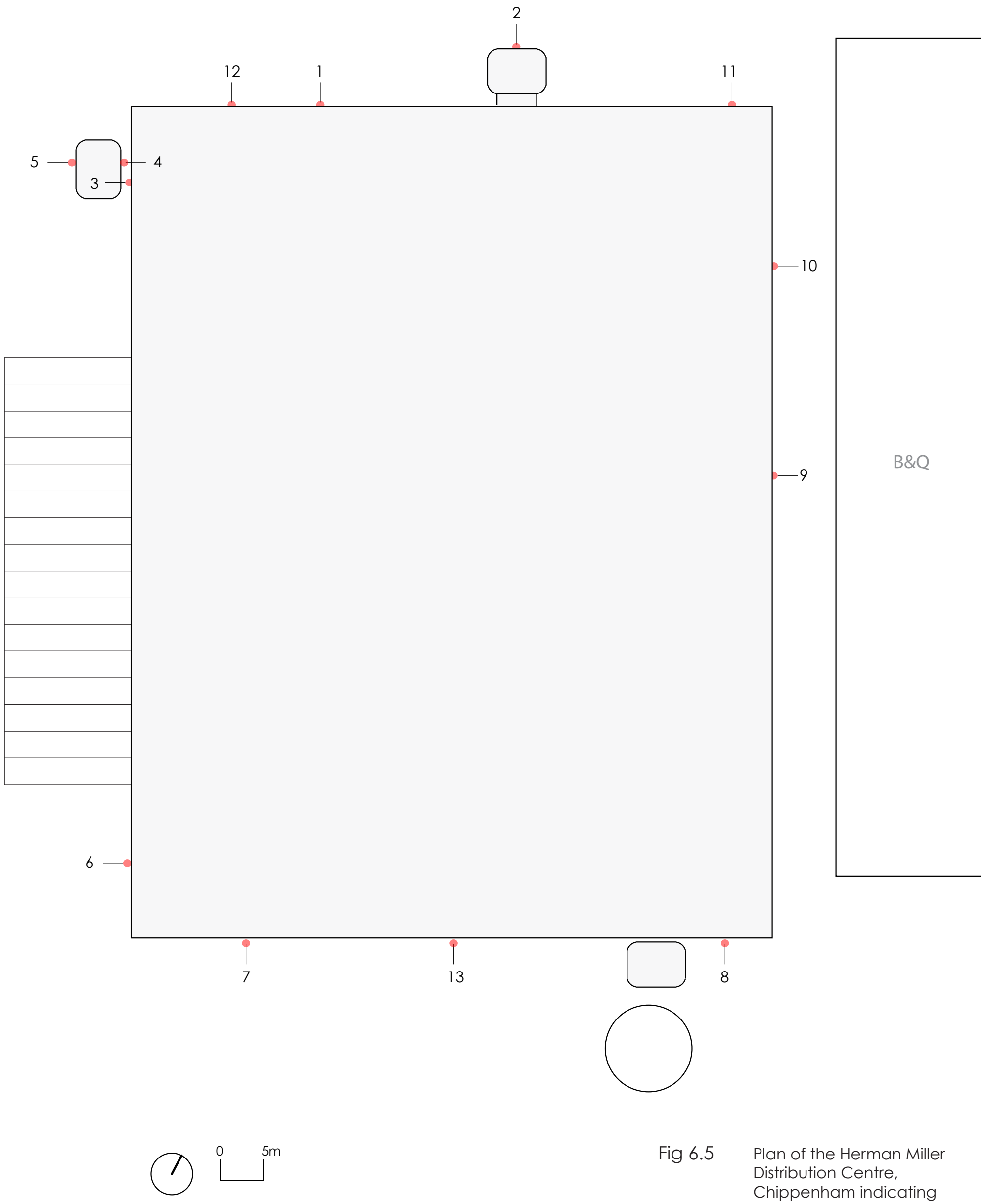


Fig 6.5 Plan of the Herman Miller Distribution Centre, Chippenham indicating the 13 sites that were tested

Exova

7.0 CONSOLIDATED TEST RESULTS - Herman Miller - Chippenham

7.1. Light Blue Panels (RAL 5012) – Colour, Gloss & Film Thickness

1 Front Aspect Colour
Panels (Light Blue)

L	A	B	E		Gloss Var	FT Var
-1.10	-1.19	-0.92	1.86		-16.47	10.15

Side aspect West. (protected behind POD) Panel Light Blue

L	A	B	E		Gloss	FT
58.09	-14.33	-31.92	67.81	**Used as STD**	54.07	56.67

6 South west façade.
Light blue panel.

L	A	B	E		Gloss Var	FT Var
-1.24	-1.58	-1.00	2.24		-34.55	5.27

7 South façade
Light blue panel.

L	A	B	E		Gloss Var	FT Var
-1.40	-1.79	-0.26	2.29		-43.33	1.99

9 East façade. B&Q side
Light blue panels

L	A	B	E		Gloss Var	FT Var
-1.68	-1.46	-1.21	2.53		-35.92	1.55

10 East façade B&Q
Light blue panels

L	A	B	E		Gloss Var	FT Var
-1.26	-1.45	-0.84	2.10		-39.17	-2.82

11 Front Aspect
Light blue cladding panel

L	A	B	E		Gloss Var	FT Var
-1.60	-1.42	-1.30	2.50		-23.03	2.72

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Client:	Michael Stacey Architects	Issue No.:	1

12 Front aspect test 3

Light blue panel

L	A	B	E	Gloss Var	FT Var
-0.42	1.02	6.21	6.31	-46.2	3.61

13 South façade. Test 2

Light blue panel

L	A	B	E	Gloss Var	FT Var
-1.23	-1.91	-1.04	2.50	-45.8	-4.89

1.1. Dark Blue Panels (RAL 5010) – Colour, Gloss & Film Thickness

2 POD

Panels (Dark Blue)

L	A	B	E	Gloss Var
0.21	-1.53	-2.26	2.74	-68.80

4 POD 2 (protected) West

Panels (Dark Blue)

L	A	B	E		Av Gloss
38.46	-5.54	-26.89	47.25	**Used as STD**	75.90

5 POD 2 dark blue panel exposed

L	A	B	E	Gloss Var
0.42	-1.60	-2.45	2.96	-69.02

8 POD 3 South

Panels (Dark Blue)

L	A	B	E	Gloss Var
0.62	-1.62	-2.16	2.77	-67.23

1.2. Cobalt Blue T-bar (RAL 5003) (Gloss & FT) window panel for colour – Colour, Gloss & Film Thickness

1 Front Aspect Colour (Cobalt)

L	A	B	E	Gloss Var	FT Var
-0.67	-0.04	-1.48	1.63	-54.97	-51.08

Cobalt

L	A	B	E	Gloss		FT
Cannot measure T-bar				62.60	**Used as STD Gloss & FT**	143.30

4 POD 2 (protected) West

Cobalt

L	A	B	E	Gloss Var	FT Var
Cannot measure T-bar				-2.60	21.40

5 POD 2 West. Exposed, Cobalt cover used for colour test

Cobalt

L	A	B	E	Gloss Var	FT Var
-0.11	-0.09	33.53	33.53	-53.65	-37.68

8 POD 3 South

Cobalt cover for colour

L	A	B	E		Gloss	FT
33.01	-2.27	-16.28	36.88	**Used as STD Colour**	-49.10	-43.13

10 East façade B&Q

Cobalt

L	A	B	E	Gloss Var	FT Var
-0.06	-0.01	-0.80	0.81	-54.55	-51.99

11 Front Aspect

Cobalt window for colour

L	A	B	E	Gloss Var	FT Var
0.50	-0.06	-0.70	0.86	-44.43	47.70

12 Front aspect test 3

Cobalt

L	A	B	E	Gloss Var	FT Var
Cannot measure T-bar				-55.35	-20.47

13 South façade. Test 2

Cobalt

L	A	B	E	Gloss Var	FT Var
2.40	0.23	0.84	2.55	-57.88	-81.31

Commentary on Test Results: Herman Miller Distribution Centre

The polyester powder-coated aluminium cladding and windows of this very successful furniture distribution centre were over 30 years old when tested in 2013. Tests were undertaken on all four elevations, ensuring that testing of all three blues specified by Nicholas Grimshaw & Partners were included on each façade.

Panels and windows:	light blue	Ral 5012
External pods:	dark blue	Ral 5010
T-bar aluminium extrusion:	cobalt blue	Ral 5003

Therefore, the test results include film thickness and colour variation for all three blues. Components of each blue were tested on all four façades. As access was only made available to the outside, a shaded area of each blue was used as the reference sample. It should also be noted that in the 1970s only gloss polyester powder coating was available.

The test on the **light blue** polyester powder-coated panels and windows revealed that the range of film thickness was quite wide: 45µm to 71µm on the north façade, 51µm to 75µm on the west façade, 43µm to 60µm on the south façade and 46µm to 65µm on the east façade.[1] This blue, which has been exposed to prolonged sunshine over 33 years, has faded. Filiform corrosion was found on the east façade only and this may have been exacerbated by the sheltering of this façade by an out-of-town DIY store, B&Q.

The test on the **dark blue** polyester powder-coated panels of the pods revealed that the range of film thickness was wide: 95µm to 101µm on the north façade, 37µm to 50µm on the west façade and 43µm to 117µm on the south façade.[2] There are no pods on the east façade and therefore no dark blue polyester powder-coated panels.

The test on the **cobalt blue** T-bar aluminium extrusion revealed that the range of film thickness was very wide: 74µm to 253µm on the north façade, 53µm to 206µm on the west façade, 47µm to 92µm on the south façade and 75µm to 134µm on the east façade.[3]

All three blues were exposed to prolonged sunshine over 30 years and have faded. This was particularly noticeable on the light blue.

The current standard for polyester powder coating in the UK and Europe is BS EN 12206-1:2004. This calls for an average film thickness of 50µm with a minimum of 40µm. Test record plates have a film thickness specified as 55µm ± 5µm. No maximum is stated in this standard.

Average test results for all the blues

Overall averages for the colour variation on the **light blue** panels:

L + = lighter − = darker	A + = redder − = greener	B + = yellower − = bluer	E Indicates how much the colour deviates from standard
56.68	-15.79	-33.22	67.38

Overall averages for the colour variation on the **dark blue** panels:

L + = lighter − = darker	A + = redder − = greener	B + = yellower − = bluer	E Indicates how much the colour deviates from standard
38.78	-6.62	-28.43	48.56

Overall averages for the colour variation on the **cobalt blue** panels:

L + = lighter − = darker	A + = redder − = greener	B + = yellower − = bluer	E Indicates how much the colour deviates from standard
33.24	-2.29	-13.05	37.36

It should be remembered that for all three blues, negative numbers in B is a good indicator as this represents a bluer colour.

For the full test results, see Appendix A.

Gloss

In 1983, all of the blues were 100 per cent gloss polyester powder coatings. In 2013, the sheltered reference samples, once cleaned, tested at the following gloss levels:

Light blue	54%
Dark blue	76%
Cobalt blue	63%[4]

The average gloss level result for light blue was 18.4 per cent, with the lowest recorded figure on the south façade of just under 8 per cent. The average gloss level result for dark blue was 7.6 per cent, with the lowest recorded figure on the west façade of just under 7 per cent. The average gloss level result for cobalt blue was 10 per cent, with the lowest recorded figure on the south façade of 4.7 per cent. It is interesting to note that the lowest gloss levels for light blue and cobalt were found on the south façade, with maximum exposure to sunshine, and on the west façade for the dark blue; the plan form of the pods might well explain this. Considering this polyester powder coating had been exposed to weathering for 30 years when tested in 2013, it is not surprising that it has faded and there has been a loss of gloss. It should be remembered that current formulations for polyester powder coating are much more durable, based on extensive research and development and long-term testing in sites of high insolation, such as Florida; see Figure 5.26 on page 176.

Notes

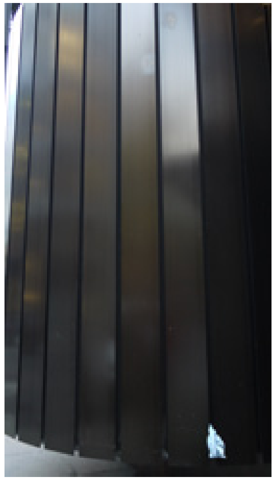
1 Results have been rounded to whole numbers. Please see Appendix A for full test results and specific values.
2 Ibid.
3 Ibid.
4 Ibid.

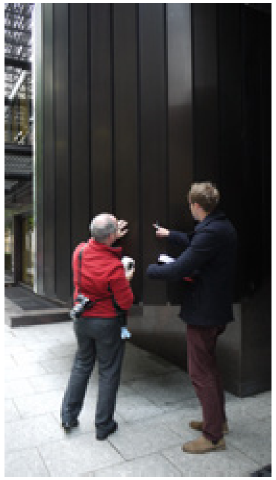
1 Finsbury Avenue, London, England: Architect Arup Associates, 1985

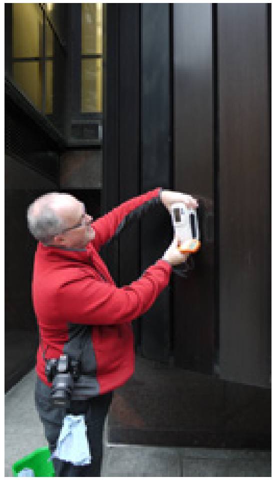
Date of testing:	7 November 2013
Time of testing:	2pm
Tested by:	Geoff Addicott, assisted by Michael Stacey and Ben Stanforth
Location:	1 Finsbury Avenue, London, England
Year of completion:	1985
Architect:	Arup Associates
Owner/client:	UBS
Weather:	Sunny and dry
Access:	Unrestricted external access, guided by Peter Hobbs, Facilities Manager
Materials and finish:	Bronze anodised aluminium extrusions forming curtain walling, cladding, brise soleil and access walkways

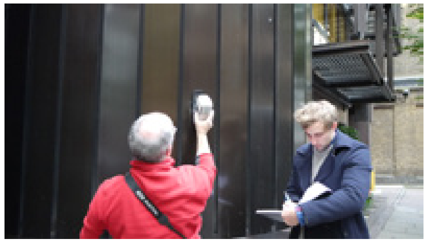
At 1 Finsbury Avenue, tests were undertaken on the bronze anodised curtain walling and extruded aluminium cladding of the stair cores from 14 sites, including all four façades, with at least two measurements per component. An original sample of the bronze anodised aluminium extrusion was tested as a base reference to compare to the test results collected. This section had been retained by project architect Rab Bennetts, who kindly lent it to the research team. A summary of results is presented on pages 250–255 and in full in Appendix A.

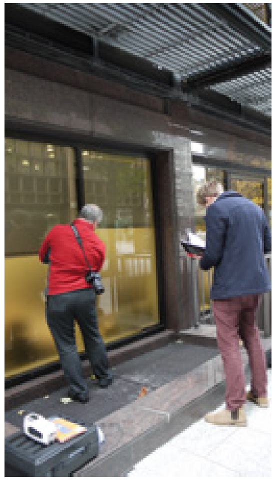
Fig 6.6 Original sample aluminium extrusion returned to site, November 2013

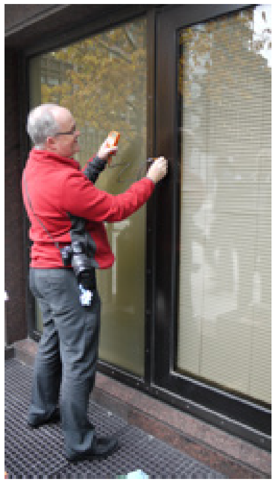












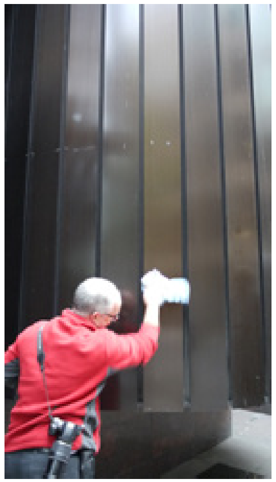


Fig 6.7 Undertaking testing at 1 Finsbury Avenue, London

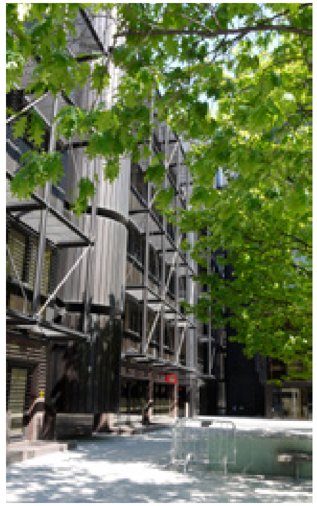
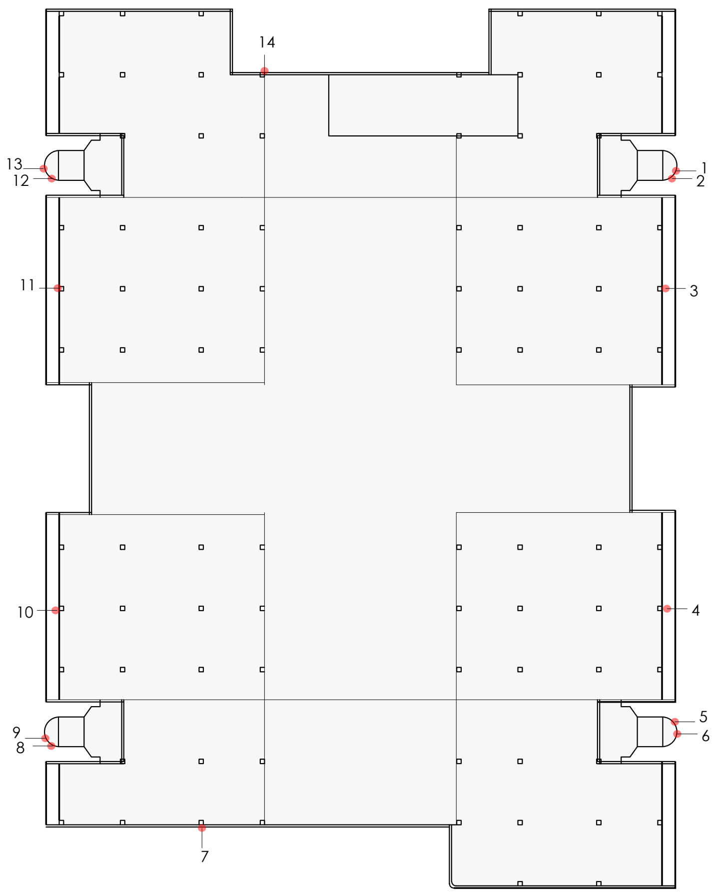


Fig 6.8 1 Finsbury Avenue

Fig 6.9 Bronze anodised curtain walling of 1 Finsbury Avenue

Peter Hobbs, Facilities Manager at UBS 1 Finsbury Avenue, with over 20 years' experience on site, observed during the test of the bronze anodised curtain walling that "1 Finsbury Avenue is the most popular UBS building with staff of all its London offices".[1] He also noted that "the curtain walling is so reliable that I have an active policy of undertaking no routine maintenance, beyond cleaning the glass. Only a few door hinges have ever needed any attention in more than 20 years."[2]



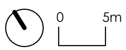


Fig 6.10 Plan of 1 Finsbury Avenue indicating the 14 sites that were tested

5.0 **CONSOLIDATED TEST RESULTS – UBS Building - London**

5.1. Test results for the Bronze Anodised finish – Colour and film thickness.

Std extrusion

L	A	B	E
29.77	2.57	4.10	30.16

Ave FT
24.3

①

L	A	B	E
-1.82	-0.64	-1.21	2.28

FT Var
-1.1

②

L	A	B	E
-4.17	-2.57	-3.76	6.17

FT Var
0.4

③

L	A	B	E
-1.83	-0.28	-0.62	1.95

FT Var
2.4

④

L	A	B	E
-0.07	0.50	1.70	1.78

FT Var
-2.1

⑤

L	A	B	E
-1.19	0.40	1.29	1.80

FT Var
-2.0

⑥

L	A	B	E
-2.48	-0.01	0.10	2.48

FT Var
-3.2

⑦

L	A	B	E
-1.31	-0.23	0.22	1.35

FT Var
2.2

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⑧

L	A	B	E
-1.59	-0.34	-0.41	1.68

FT Var
-4.1

⑨

L	A	B	E
0.49	0.73	2.22	2.39

FT Var
-1.8

⑩

L	A	B	E
-0.69	-0.47	-1.02	1.32

FT Var
0.1

⑪

L	A	B	E
0.01	0.24	1.32	1.34

FT Var
-3.3

⑫

L	A	B	E
-1.01	-0.18	-0.64	1.21

FT Var
-1.9

⑬

L	A	B	E
-0.05	0.21	1.02	1.04

FT Var
4.5

⑭

L	A	B	E
1.03	-0.70	0.45	1.32

FT Var
1.1

For details of film thicknesses beyond the sample extrusion, please see Appendix A.

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Client:	Michael Stacey Architects	Issue No.:	1

Commentary on Test Results: 1 Finsbury Avenue

This very successful and popular office building in the City of London, currently occupied by UBS, was completed in 1985, and so this curtain-walling assembly was over 28 years old when tested. Project architect Rab Bennetts stated that only a very brief specification was prepared for this curtain-walling system by Arup Associates, and in essence Peter Foggo of Arup placed his and his client's trust in Hans Seidenstoff of Josef Gartner.[3] The bronze anodised aluminium components of the curtain walling were tested on all four façades. The north and south façades are sheltered and not washed by rainwater. The bronze anodised extruded aluminium cladding is specific to the curved fire escape towers. These occur twice on the long façades (the east and west façades).

The thickness of the bronze anodising on the curtain walling ranged from 19μ to 37μ, with an average value of over 25μ. The reference sample exhibited a range of 22μ to 26μ, with an average value of just over 24μ. Intriguingly, the sample section that had been indoors for the previous 28 years, prior to its return to site for testing, was just below the standards set in BS EN ISO 7599:2010 for 25μ external anodising, which requires a minimum of 80 per cent of the specified thickness of 20μ and an average equal to or greater than the specified value of 25μ. It should be noted that this was only a short section of anodised aluminium extrusion. The curtain walling sections tested were within the standards set by BS EN ISO 7599.

The thickness of the bronze anodising on the aluminium extrusions enclosing the fire escape towers ranged from 16μ to 33μ, with an average value of just over 23μ. The bronze anodised aluminium extrusion sections tested were below the standards set by BS EN ISO 7599, with a measured minimum thickness of 16μ, 4μ below the standard, and with an average thickness of 23μ, 2μ below the standard. It was, however, easily above the standard in BS EN ISO 7599 for anodising specified at 15μ (an option in this standard). The unwashed anodising on the sheltered façades was appreciably rougher than that on the façades cleaned by rainwater. UBS, the current occupiers of 1 Finsbury Avenue, confirmed that this anodising is not cleaned annually; only the glass is cleaned periodically.

Both the bronze anodised aluminium curtain walling and extruded aluminium cladding were tested for variations in colour. Only the bronze anodised extruded aluminium cladding exhibited colour variation to the human eye.

Average for the colour variation on the sample curtain-walling extrusion:

L	A	B	E
+ = lighter – = darker	+ = redder – = greener	+ = yellower – = bluer	Indicates how much the colour deviates from standard
29.77	2.57	4.10	30.16

Overall averages for the colour variation on the curtain-walling extrusions:

L	A	B	E
+ = lighter – = darker	+ = redder – = greener	+ = yellower – = bluer	Indicates how much the colour deviates from standard
29.29	2.42	34.44	29.74

Thus, the curtain walling performed very similarly to the reference sample, which has not been exposed to the weather. It should be noted that no negative numbers were recorded, so the curtain walling appeared not to have darkened, becoming neither greener nor bluer.

As a sample of the bronze anodised extruded aluminium cladding had not been retained, the same sample was used as a reference, based on Arup Associates seeking to produce a family of components all with the same finish and colour or colour range.

Overall averages for the colour variation on the extruded aluminium cladding:

L	A	B	E
+ = lighter – = darker	+ = redder – = greener	+ = yellower – = bluer	Indicates how much the colour deviates from standard
27.98	2.11	3.56	28.35

Thus, the extruded aluminium cladding performed similarly to the reference sample, which has not been exposed to the weather. It should be noted that no negative numbers were recorded, so the curtain walling appeared not to have darkened, becoming neither greener nor bluer. However, specific extrusions recorded very low values for redness and yellowness, confirming the perception of the human eye. The Towards Sustainable Cities Research Team cannot confirm that this is a result of exposure to the sun and urban atmosphere of the City of London, as a range of samples of the bronze anodising were not retained.

It should be noted that this anodised curtain-walling assembly is not periodically cleaned by UBS. It is performing very well after 28 years of service in urban London.

Notes

1 Comments recorded by Michael Stacey during the site testing, 7 November 2013.
2 Ibid.
3 Correspondence between Rab Bennetts and Michael Stacey prior to the site testing, 7 November 2013.

SEVEN

aluminium, maintenance and durability

Aluminium, Maintenance and Durability

This chapter examines the role of maintenance in durability, reviewing the results of this research programme. It concludes with comparative maintenance data on timber, PVCu, steel and aluminium, placing an emphasis on window assemblies. Recommendations for maintenance cycles are included for each material.

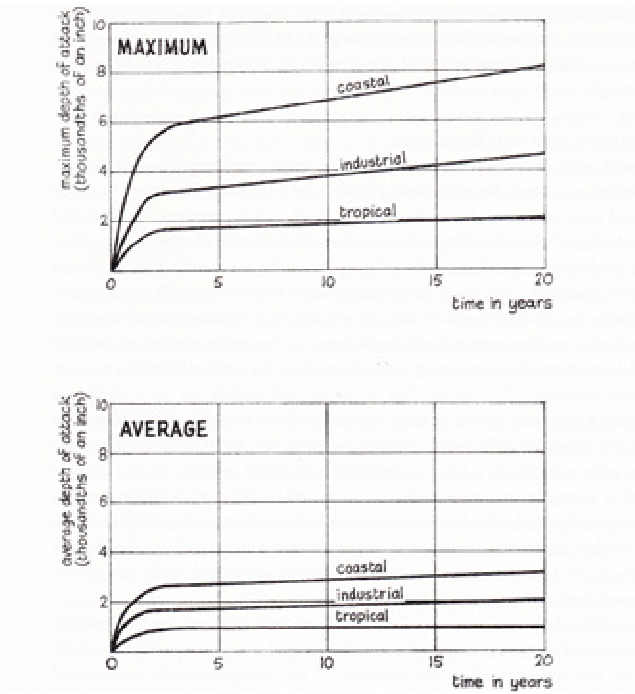


Fig. 7.1 Graphs showing the weathering of aluminium alloy NS3

In *Light Cladding of Buildings* (1964), R. Michael Rostron observes that 'the weathering of aluminium is not yet fully understood and there exist many misconceptions about the protection offered by anodising'.[1] He includes a very pair of useful graphs illustrating the weathering of aluminium alloy NS3 (equivalent to 3103 in contemporary nomenclature), showing the average and maximum depth of pit corrosion, to the thousandth of an inch, in coastal industrial and tropical atmospheres. The source of this data is not declared and the time span of 20 years presumably reflects the period since the later stages of the Second World War. For example, the AIROH prefabricated house prototypes were 20 years old at the time of *Light Cladding of Buildings*' publication. It is also interesting to note that the depth of the average pit corrosion appeared to be plateauing at between five and 15 years, with tropical climates the most stable. This is because there the aluminium is 'washed' by frequent rainfall.

Fig. 7.2 The mill-finish aluminium cladding of the dome of San Gioacchino, Rome,1897, architect Raffaele Ingami

Fig 7.3 Postsparkasse, Vienna, architect Otto Wagner, 1906. The first world-class work of architecture to use aluminium

Rostron also appears to have been unaware that the aluminium cladding of the cupola of San Gioacchino in Rome, built in 1897 in honour of Pope Leo XIII, had been tested in 1949 after 52 years of exposure to a polluted, industrial and urban environment. A maximum depth of pit corrosion was noted at only 0.8mm out of a 1.3mm sheet thickness. The sculpture of Eros at Piccadilly Circus in central London was cast from a high-purity aluminium and installed in 1893. When the sculpture was cleaned for the coronation of Queen Elizabeth II in 1953, having been exposed to heavily polluted atmosphere of London for 60 years, the aluminium was found to be in excellent condition with no evidence of pit corrosion. In 1986, Eros was repaired by Charles Henshaw & Sons in Edinburgh because vandals had broken his outstretched leg.[2]

Rostron recognises that 'anodised surfaces are easier to keep clean' than mill-finish aluminium, 'provided cleaning is regularly carried out'.[3] However, he also asserts that 'it is doubted whether it is worth an additional 15 per cent outlay' to clean the frames as well as the glass. The basis for this costing, and the assertion that cleaning is not worth carrying out, are left unsubstantiated. It should be noted that all contemporary guarantees for aluminium finishes require regular cleaning. For instance, Qualicoat recommend cleaning at the following frequencies:

- normal environment – clean every 12 months;
- marine and/or industrial environment – clean every three months;
- swimming and leisure pools – clean every three months.[4]

It is interesting to compare Rostron's text with the current testing of early Kalzip projects by the German Federal Institute for Materials Research and Testing [BAM].[5] Kalzip aluminium roofing is roll-formed from an aluminium sheet, which has had an additional top layer of AlZn1 (aluminium zinc alloy) of approximately 5 per cent of the thickness rolled onto the base material under high pressure and at a temperature of approximately 500°C. Both materials are welded in the process; the structure of the sacrificial alloy becomes so diffused into the base aluminium that no separating layer exists any more. The improved corrosion protection comes from the negative potential of AlZn1 of 150 mV towards the base material of AlMn1Mg1.

Fig. 7.4 Sculpture of Eros at Piccadilly Circus, 1893, central London

The research undertaken by BAM involved the testing of samples of Kalzip aluminium roofing from the three earliest Kalzip projects in Europe. Kalzip aluminium standing-seam roofing is an American invention that was first used to roof the Nuremberg Congress Hall, a surviving fragment of a massive Nazi master plan. The aluminium standing-seam roofing was installed in 1968 and so is now over 45 years old, see page 89. BAM reported that 'the pitting corrosion effects in the plating layer detected in the cross section stop at the bulk material and thus do not affect the function of the roofing after 41 years of use [testing occurred in 2009] ... long durability can be expected.'[6] They also tested a packing hall in Hamburg, built in 1970, see page 92. This aluminium standing-seam roof has been exposed to an industrial and maritime environment for 45 years. BAM found that 'After 40 years of exposure, the bulk material is not yet affected ... At the present moment the function of the roof is completely in a good condition.'[7] Tests were carried out after a little more than one year of exposure, in 1972, and early signs of pitting corrosion were found. When the roof was tested again in 1992, further pitting was noted but the core material remained unaffected. The most recent test in 2009 showed that 'pitting and corrosion is restricted to the protective layer; the bulk material remains completely unaffected'.[8] The third project to be tested by BAM was a storage facility in Essen, built in 1974, see page 93. The report observed that 'the investigations reveal numerous corrosion effects which, however, do not extend to the bulk material'.[9]

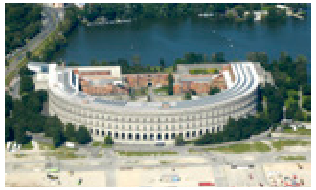


Fig 7.5 Nuremberg Congress Hall, architect Ludwig and Franz Ruff, 1968, the first use of Kalzip in Europe

The only formal definition of an antique in the world is provided by the US Federal Tax organisation: 'an object or artefact over 100 years old'.[10] The sculpture of Eros in London is 122 years old and the cupola of San Gioacchino in Rome is 118 years old; even the Postsparkasse in Vienna is 109 years old. Many contemporary texts on architecture and construction still refer to aluminium as a new material, and perhaps it is in comparison to granite from Scotland that is 3,000 million years old. However, in the valued judgement of architects and designers, aluminium should be recognised as a material that is very durable, particularly if the stewardship of the owners or managers of aluminium-based architecture and infrastructure is well informed, and regular cleaning and annual inspection are undertaken.

There appears to be a need for the aluminium component industry to undertake further research on aluminium alloys and the effects on the durability of the other metals included in these alloys to improve performance characteristics other than durability.

The majority of the projects visited during the course of this research, even those that have access equipment such as integrated cradle systems, show no sign of periodic cleaning of the aluminium components. It should be noted that many of these projects had access systems installed before this became a requirement under CDM Regulations (in the UK). During the course of this research, only two case study buildings were found to be well maintained, with the cladding and glazing being regularly cleaned: George House in London and Imperium in Reading. The other recorded case of regular cleaning of cladding and glazing was the Holiday Inn Express in Nottingham, England, organised by the facility managers, CBRE Richard Ellis.

Therefore, a vital question is: how can building owners and mangers be encouraged to follow the guarantees on aluminium finishes, which are appropriately predicated on regular cleaning? Often such guarantees are carefully and sometimes expensively organised during the construction contract, including collateral warranties. Yet they are often negated in the first years of ownership due to a lack of cleaning. An under-discussed aspect of sustainability is the stewardship of architecture and infrastructure by building owners and managers.

Fig 7.6 Holiday Inn Express, Nottingham: abseilers cleaning the aluminium cladding, 13.53pm on 6 October 2012

Comparative Maintenance Analysis of Painted Timber, PVCu, Painted Steel and Aluminium for Door and Window Frames

This section identifies the current good and best practice in the maintenance of painted timber, PVCu, painted steel and aluminium. Typically, these materials form the glazing sections of windows and doors. The sources of the data are set out in the text and bibliography. The purpose of this comparative maintenance analysis is to inform a Life Cycle Assessment [LCA] for each material with a good level of granularity (the best of current data). The LCA will be the subject of a later report and paper in this research programme; see Towards Sustainable Cities Report 3 (2015).

This comparative analysis has been undertaken from the perspective of an architect who is interested in specific appropriate materials for the new windows of a project, such as an office, home or school. Trade and manufacturers' data have been used and analysed for both comparative benefits and relative disadvantages. The time period between maintenance tasks has been established, including the relative difficulty of undertaking such tasks. Some maintenance factors, such as the longevity of window gaskets, which needs to be the subject of wider research into built fabric durability for windows and curtain walling, are outside the scope of this current research. In all cases, CDM Regulations (in the UK) are considered to be operative and thus safe and easy access is available for this maintenance. Therefore, there is no need to factor in the erection of scaffolding or the hire of a cherry picker, as is often required on older properties.

Fig 7.7 Steel balconies being maintained at Park Rock, Nottingham, while the aluminium window frames do not need any maintenance beyond cleaning

Table 7.1 [right] Comparing good practice and best practice maintenance principles for painted timber, PVCu, steel and aluminium

Material	Material Advantages	Good Practice	Best Practice
Painted Timber	Timber is cut and seasoned sections of trees. It is primarily composed of cellulose, hemicellulose and lignin. Species selection is very important. Typically timber needs to be protected from moisture ingress and photodegradation by the UV rays in sunlight. The Wood for Good campaign, which works on behalf of the whole timber industry in the UK, claims that wood scores better in Life Cycle Assessments [LCA] than other materials, while offering low maintenance, long-life durability and simple reparability. [11] Timber windows can be supplied directly from the factory with a range of finishes, including base coat stains offering short-term protection prior to on-site finishes or full finishes with varying stains or paint colours. Can be reused but cannot be recycled,	Inspect windows regularly. Cracked and flaking paintwork: the outside of the windows should be repainted at intervals of five to eight years, normally. Once four layers of paint have accumulated, paint should be stripped off before repainting. Sticking windows: usually the result of either careless replacement of staff beads, following repair or re-cording, which is easily remedied, or a build-up of paint that needs to be removed. Failed putty and broken glass panes: these are relatively easy to replace. Broken sash: previously people re-corded their own windows – the cords and sash weights were available at any ironmongers (and still are at some). Timber decay, particularly to the bottom rail: fillers are invaluable for minor decay and surface imperfections, where the strength of the timber is unaffected; loose corner joints can be strengthened by means of corner brackets which can then be painted over; and more significant repairs can be carried out by any competent joiner.[12]	Inspect windows regularly. Treat timber with a microporous system e.g. Dulux Weathershield Exterior Preservative 203 Primer+. This is a three-paint system: 1 Prepare surface: clean and dry before treating. Remove all loose and defective coatings, if necessary stripping back to bare wood. Remove and treat any mould, algae, lichen or moss. 2 Prime all bare wood with one coat of Weathershield Exterior Preservative Primer+. 3 Apply one coat of the appropriate coloured Weathershield Exterior Undercoat to all primed wood. 4 Apply a second coat of Weathershield Exterior Undercoat. 5 Weathershield Exterior High Gloss or Weathershield Exterior Quick Drying Satin. Allow a minimum of two hours before over coating Weathershield Exterior Undercoat or Weathershield Exterior Quick Drying Satin, and 16 hours for Weathershield Exterior High Gloss. [13] Guarantee: eight years for High Gloss and six years for Quick Drying. [14] Sadolin Woodshield provides an alternative one-paint system. It provides eight years of protection, with the microporous technology allowing deep protection from within the timber. It is both self-priming and undercoating, becoming more efficient than other alternatives. The formula erodes over time, requiring just a recoat; no stripping or sanding or scraping is required. [15] This coating system requires two coats.

Material	Material Advantages	Good Practice	Best Practice
PVCu	Extrudeable thermoformable polymer. The British Plastics Foundation states that PVCu windows and doors are: • Tough, durable and designed to give a long life in a home; • Low maintenance – just occasionally wipe it clean; • Energy efficient – meets all the latest requirements for thermal efficiency. Limited capacity for recycling.	PVCu maintenance falls under two categories that should be carried out on an occasional basis: **A] Surface maintenance** Clean frames to remove dirt: PVCu elements should be cleaned regularly using a non-abrasive detergent solution. **B] Functional maintenance** Lubrication of internal systems including hinges and locking systems: ensure moving parts continue to operate correctly. Drainage: make a visual inspection to ensure the built in drainage system is kept clear of debris. Gaskets and seals: make a visual inspection to ensure that the weather seals are undamaged and have not become dislodged.	PVCu maintenance falls under two categories that should be carried out on an regular basis: **A] Surface maintenance** Clean frames to remove dirt: PVCu elements should be cleaned regularly using a non-abrasive detergent solution. Surface maintenance kits are available for repairing indentations and scratches. These contain hard and soft waxes, brushes, lacquer pens, gas heating irons and wire wool. When cleaning PVCu with woodgrain or coloured finishes, do not use abrasive cleaners as these can affect the overall finish of the element. **B] Functional maintenance** Lubrication of internal systems including hinges and locking systems: ensure moving parts continue to operate correctly. Hinges, handles, locks and drainage systems can be replaced without the need to replace the whole PVCu element. Drainage: make a visual inspection to ensure the built in drainage system is kept clear of debris. Gaskets and seals: make a visual inspection to ensure that the weather seals are undamaged and have not become dislodged Example guarantee: Vantage Doors and Windows offer a guarantee of ten years on the factory product.[16]

Material	Material Advantages	Good Practice	Best Practice
Steel	A hard strong and ductile metal: iron with 0.2 -1.5% carbon. Corrodes rapidly if not protected. Offers stiffness and narrow sightlines. It is almost infinitely recyclable.	Steel windows and doorframes should be washed down at the same time as window cleaning takes place, between every three and twelve months. An inspection on working parts should be carried out annually.	There are two types of finishes for steel windows: **A] Factory finishes** Polyester powder colour coating requires a simple wash using a mild non-alkaline detergent in warm water, applied with a soft cloth or sponge. Recoating of the polyester powder colour coating should only be required between 10 to 20 years, if nothing harsher than a bristle brush is used to clean the steel. **B] On-site finishes** Bare galvanised windows supplied on site require zinc chromatic etched primer prior to further brush paint coats. The steel frames are supplied with clearances allowing up to four coats of paint; after the fourth coat the paint should be removed to ensure that moveable elements of the frame do not become stuck shut.[17] Crittall Windows advise: 'When renovating an older steel window, all traces of old paint should be removed, starting with a wire brush, then using wire wool and finally wet & dry paper. Zinc-rich paint should then be applied to any part of the frame with damage to the galvanised finish; the frame can then be painted with zinc phosphate-rich primer, and undercoat and exterior quality paint of the type developed for metal.' [18]

Material	Material Advantages	Good Practice	Best Practice
Aluminium	Aluminium is a light metal that is very flexible in terms of design and fabrication. It has a high strength to weight ratio, especially when alloyed to other metals or elements. Sections for windows and doors are typically 6000 series alloys with aluminium principally combined with magnesium and silicon. Aluminium offers good site lines and extrusions can readily incorporate details for gaskets and other functions. It is very durable when mill finish or coated. Case studies in this research reveal that aluminium has an in-use service life of between 80–120 years. Aluminium is almost infinitely recyclable.	Good practice should follow the British Standard for Powder Coating on Aluminium for External Use, BS 6496: 1984 (1991) states that cleaning should be carried out every six months.[18] Smart Systems advice on maintenance includes: 'In areas where aluminium is in an area directly under the influence of salt water, industrial chemical plants, blast furnaces or other aggressive emission sources, the windows should be cleaned once every three months.'[19] Recommending that internal elements of aluminium windows and doors should also be regularly cleaned. Frames should be maintained as follows: • Wash with clean warm water containing a non-alkaline liquid detergent using a non-abrasive cloth, brush or sponge. • Rinse with clean water. • Dry using a soft cloth or leather.[20]	Qualicoat represents international best practice and outlines maintenance/cleaning times for different environments. As a guide, in each environmental context the following cleaning cycle should followed: • Normal: 12–24 months; • Marine: 3–12 months; • Industrial: 3–12 months; • Swimming pools: 3 months.[22] Qualicoat advice includes: 'clean the surface using a soft brush or non-abrasive cloth and a neutral mild household or neutral car wash detergent, following the supplier's instructions. After cleaning, rinse the surface thoroughly with fresh water.'[23] Drying is not stated, however, Qualicoat advise that cleaning should be carried out by specialised cleaning companies.[24]

Notes

1 R. M. Rostron (1964), *Light Cladding of Buildings*, Architectural Press, Oxford, p. 177.
2 S. Clarke (1994), *The restoration of Eros*, Context, 42, pp. 23–24, available online at http://ihbc.org.uk/context_archive/42/clarke.htm (accessed August 2013).
3 R. M. Rostron (1964), *Light Cladding of Buildings*, Architectural Press, Oxford, p. 178.
4 Qualicoat (2011), *Recommendations for Care of Coated Aluminium*, available online at www.qualicoat.net/main/downloads.html (accessed August 2013).
5 Kalzip Ltd (2011), *Durability and Corrosion Testing*, available online at www.kalzip.co.uk/PDF/uk/BAM%20Durability%20and%20corrosion%20testing.pdf (accessed September 2015).
6 Ibid.
7 Ibid.
8 Ibid.
9 Ibid.
10 As defined in the 1930 Smoot–Hawley Tariff Act.
11 Wood for Good (2013), *Why Use Wood?*, available online at www.woodforgood.com/why-choose-wood (accessed July 2013). See Towards Sustainable Cities Report 3 *Aluminium and Life Cycle Thinking* for further analysis of comparative LCAs.
12 D. Wrightson (2001), *Sash Windows: Painting and Draught-Proofing*, available online at www.buildingconservation.com/articles/sashwindows/sash_windows.htm (accessed July 2013).
13 Dulux Trade (2008), *Weathershield Exterior Preservative Primer+*, available online at http://dulux.trade-decorating.co.uk/web/pdf/datasheets/203.pdf (accessed July 2013).
14 Dulux Trade, *Weathershield*, available online at www.duluxtradepaintexpert.co.uk/brands/dulux-trade/weathershield (accessed September 2015).
15 Sadolin (2012), *Woodshield*, available online at www.sadolin.co.uk/wp-content/uploads/data-sheets/sadolin-woodshield-technical-data-sheet.pdf (accessed July 2013).
16 Vantage Windows and Doors, *Warranty and Service*, available online at www.vantagedoorsandwindows.co.uk/warranty-service.html (accessed July 2013).
17 Steel Window Association, *Aftercare and Maintenance of Steel Windows*, available online at www.steel-window-association.co.uk/assets/files/fs4.pdf (accessed September 2015).
18 Crittall Windows, *Maintenance of Steel Windows*, available online at www.crittall-windows.co.uk/products/maintenance-of-steel-windows (accessed September 2015).
19 Architectural Powder Coatings (2008), *Maintenance of Powder Coated Aluminium Articles*, available online at http://architecturalpowdercoatings.co.uk/docsblog/docsblog/index_files/New%20Maintenance%20Sheet.pdf (accessed July 2013).
20 Smart Systems (2005), *Cleaning, Maintenance and Repair: Aluminium Windows, Doors and Architectural Products*, available online at www.smartsystems.co.uk/asset/?id=133 (accessed September 2013).
21 Ibid.
22 Qualicoat (2013), *No. 1: Guide for Cleaning and Maintenance of Powder Coated Aluminium*, available online at www. qualicoatuki.org/downloads_files/01_cleaning_1301.pdf (accessed July 2013).
23 Ibid.
24 Ibid.

Dornier Do 17 Pencil (Aircraft): Extreme Durability Case Study

The Dornier Do 17, sometimes referred to as the '*Fliegender Bleistift*' ('Flying Pencil'), was a Second World War German light bomber produced by Claudius Dornier's company, Dornier Flugzeugwerke.

Wingspan:	18m
First flight:	1934
Introduced:	1937
Obsolete:	1944
Manufacturer:	Dornier Flugzeugwerke

The extensive remains of the only known Dornier Do 17 aircraft were raised off the seabed on 12 June 2013, from the Goodwin Sands off the Kent coast, England, by a salvage team working for the RAF Museum. It had been on the seabed since 26 August 1940, when it was shot down in the Battle of Britain. Of the crew, two Germans sadly lost their lives, and two were captured and became prisoners of war.[24]

The alumimium alloy structure and skin of the last remaining Dornier Do 17 is believed to have substantially survived over 60 years on the seabed in salt-rich seawater as German industry during the Second World War was forced to use a high purity of aluminium due to a lack of other metals to form alloys. The use of copper alloyed to aluminium is known to reduce the durability of uncoated aluminium when exposed to water. Duralumin is an example of an aluminium alloy that uses copper in the alloy to improve strength characteristics and has the additional benefit of being able to be age-hardened. Does the survival of this Dornier Do 17 in saltwater for over 60 years indicate that aluminium is more durable than current texts suggest?

Further Research Action

A. Is aluminium more durable than current texts and data suggest?

Fig 7.8 Dornier Do 17

Fig 7.9 Spitfire

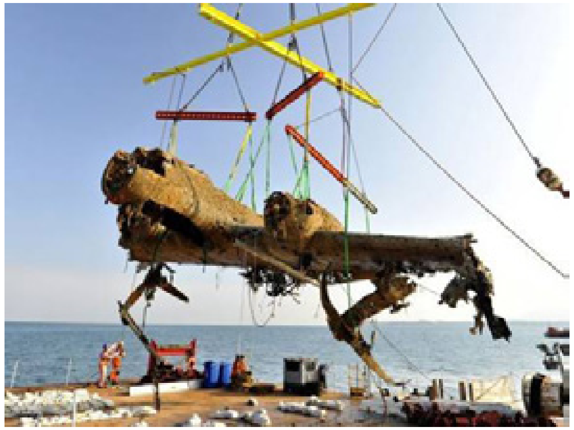


Fig 7.10 Dornier Do 17 being salvaged from the English Channel, 2013

Fig 7.11 Dornier Do 17, salvaged from the English Channel, 2013

EIGHT

aluminium finishes guarantees

Guarantees of Aluminium Finishes

The guarantees of finishes on aluminium offered by the industry's leading fabricators and finishers are set out in this chapter, on a global yet regional basis. The sample of companies includes manufacturers and applicators that offer guarantees for anodised, polyester powder-coated and PVDF finishes. The sources of the data are set out in the notes. The purpose of exploring the finishing guarantees is to add to the Life Cycle Assessment [LCA] and to explore whether maintenance of aluminium is required, recommended or not specified within these guarantees and whether guarantees vary due to location.

The notion of guarantees within the construction industry has become increasingly complicated, with a division of the production chain existing between manufacturers and applicators. For instance, polyester powder coatings are guaranteed by the manufacturer, for example Valspar, but this guarantee is invalid unless applied by an approved applicator, such as Powdertech, with the addition of adhesion and corrosion guarantees included to activate the manufacturer's guarantee. The table below shows the guarantees of the industry's leading aluminium finishers. The guarantees provided by the aluminium finishing industry, in this study, relate to Anodising British Standards and American Architectural Manufacturers Association Standards (see notes).

Interpon's polyester powder coatings have different lengths of guarantee depending on which environment of atmospheric corrosivity the polyester powder coating is located in, as classified by the ISO 12944 Paints & Varnishes – Corrosion Protection of Steel Structures by Protective Paint Systems (Parts 1–8),1998.[1]

ISO 12944 Classification	Atmospheric Corrosivity	Typical Environment
C1	Very low	Heated buildings and areas of neutral atmosphere (internal)
C2	Low	Rural areas and areas of low pollution
C3	Medium	Urban and industrial atmospheres with moderate sulphur dioxide levels and production areas with high humidity
C4	High	Industrial and coastal chemical processing plants
C5-I	Very high (industrial)	Industrial areas with high humidity and aggressive atmospheres
C5-M	Very high (marine)	Marine, offshore, estuaries, coastal areas with high salinity

Table 8.1 Categories of Atmospheric Corrosivity in accordance with ISO 12944

Company	Aluminium Finish	Range	Region	Specific Environment	Additional Requirements	Guarantee
United Anodisers (anodisers)[2]	Anodised	Anolok and Anolok II[3]	Europe	Cannot be placed in direct influence zones of acid or industrial or other aggressive emissions		Building lifetime – this can be related to BS 7543
Valspar (manufacturers of Syntha Pulvin)	Polyester powder coated (satin, metallic, matt)	Syntha Pulvin Standard	Europe North of 48°N (just south of Paris)		Guarantee in relation to BS1470, BS1471 and BS1474	
		Syntha Pulvin Premium	UK		Guarantees are provided by both Valspar and the approved applicator[4]	
			Worldwide			Project Specific
Powdertech (applicators)	Polyester Powder Coated	Syntha Pulvin Standard	Europe North of 48°N (just south of Paris)			30 years
		Syntha Pulvin Premium				40 years
Interpon[5] (manufacturers)	polyester powder coated	D1036	Normal – C3 Inland (worldwide)			10 years
			Marine – C4 Costal (worldwide)	2000m – 5000m from coastline	Clean every 12 months	10 years
				500m – 2000m from the coastline	Clean every 6 months	10 years
				50m – 500m from the coastline	Clean every 3 months	5 years
				Less than 50m from the coastline		Not available
			Industrial C5-I (worldwide)	2000m – 5000m from source of pollution	Clean every 12 months	10 years
				500m – 2000m from the coastline	Clean every 9 months	10 years
				50m – 500m from the source of the pollution	Clean every 3 months	5 years
				Less than 50m from the source of the pollution		Not available
			Swimming Pools (worldwide)	More than 2m from the pool	Clean every 3 months	5 years
				Less than 2m from the pool		Not available

Company	Aluminium Finish	Range	Region	Specific Environment	Additional Requirements	Guarantee
Interpon (manufacturers)	Polyester powder coated	D2525[5]	Normal – C3 Inland (worldwide)			15 years
			Marine – C4 Costal (worldwide)	2000m – 5000m from coastline	Clean every 12 months	15 years
				500m – 2000m from the coastline	Clean every 9 months	15 years
				50m – 500m from the coastline	Clean every 3 months	10 years
				Less than 50m from the coastline		Not available
			Industrial C5-I (worldwide)	2000m – 5000m from source of the pollution	Clean every 12 months	15 years
				500m – 2000m from source of pollution	Clean every 9 months	15 years
				50m – 500m from source of the pollution	Clean every 3 months	10 years
				Less than 50m from source of the pollution		Not available
			Swimming Pools (worldwide)	Greater than 2m from the pool	Clean every 3 months	10 years
				Less than 2m from the pool		Not available
		D3000 Fluromax	Normal – C3 (worldwide)			20 years
			Marine – C4 Costal (worldwide)	2000m - 5000m from the coastline	Clean every 12 months	20 years
				500m – 2000m from the coastline	Clean every 9 months	20 years
				50m - 500m from the coastline	Clean every 3 months	15 years
				Less than 50m from the coastline		Not available
			Industrial C5-I (worldwide)	2000m - 5000m from source of the pollution	Clean every 12 months	20 years
				500m - 2000m from source of the pollution	Clean every 9 months	20 years
				50m – 500m from source of the pollution	Clean every 3 months	15 years
				Less than 50m from source of the pollution		Not available
			Swimming Pools (worldwide)	More than 2m from the pool	Clean every 3 months	15 years
				Less than 2m from the pool		Not available
PPG Duranar (manufacturers)	PVDF (thermoplastic fluoropolymer)	Duranar XL coatings	USA	AAMA 2603[6]		5 years
				AAMA 2604[6]		10 years
				AAMA 2605[6]		20 years

The period of guarantee provided for the finishes of external aluminium components worldwide varies for two main reasons. The first reason is variability between the regulations and laws of specific countries, which are a function of the context, including market forces and legal traditions, and have as great an influence as the physical performance of the finish.

The second reason is variability between regional climates: the amount of sunshine, annual and diurnal temperature ranges and the quantity of beneficial rainwater washing the exposed surface of the finished aluminium. Regions of high insolation, such as Florida and the Middle East, can prove a challenge for colourfastness in particular. Areas of high rainfall, including the Tropics, can be beneficial to the durability of finished aluminium as the exposed surface is frequently washed by rainwater. Annual thermal variation is also important; thus, a finish in a more stable, maritime climate will be less stressed than a finish in a continental climate with very cold winters and very hot summers.

Based on the research presented in this report, it can be concluded that carefully specified and tested finished aluminium is extremely durable and that its functional service life (at least as far as surface finishing is concerned) is significantly longer than the guarantee periods provided at the time of project specification.

Notes

1 These environments are based on experiments that have measured the rate of metal loss for uncoated steel. The classification of environments applies to structural steel exposed to ambient (less than 120°C/248°F) conditions.

2 United Anodisers were formed in 2007 when LHT Anodisers and Heywood Metal Finishers amalgamated.

3 United Anodisers, *Lifetime Guarantee*, available online at www.unitedanodisers.com/index.php/the-ua-group/lifetime-guarantee.html (accessed September 2015).

4 Syntha Pulvin, *Guaranteed Downloads*, available online at www.synthapulvin.co.uk/?ret_page=www.synthatec.com/technical/guaranteed_performance.asp (accessed September 2015).

5 *Interpon D Brochure*, available online at www.interpon.co.uk/expertise-centre-downloads (accessed September 2015).

6 In the USA the industry coating aluminium extrusions and panels, for the most part, follows the specifications set by the American Architectural Manufacturers Association [AAMA]. They have three main levels of performance and each of these has a weathering performance factor. Warranties in general follow these specifications and coatings companies generally cover three areas: AAMA 2603 – specification requirement for weathering, 1 year south Florida testing; AAMA 2604 – specification requirement for weathering, 5 year south Florida testing; AAMA 2605 – specification requirement for weathering, 10 year south Florida testing.

NINE

interim conclusion

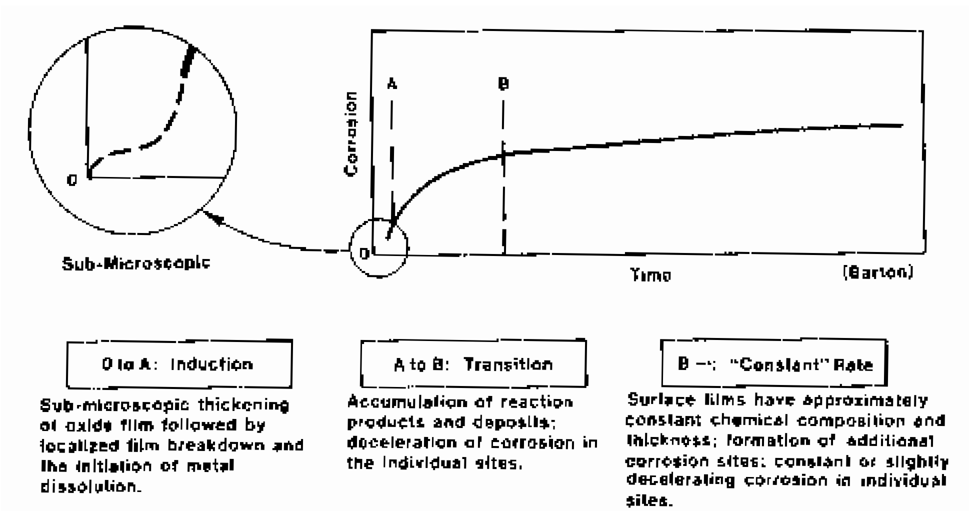
Interim Conclusion

Set out below is the interim conclusion of this research, including recommendations for further actions, particularly for the aluminium fabrication and finishing industries.

The durability of mill-finish aluminium exposed to the weather is influenced by a range of factors. This has been studied over time and in many parts of the world.[1] The starting point for the consideration of aluminium and durability is the alloy itself; in simple terms, the purer the better. The introduction of other metals such as copper, to improve strength, reduces the durability of the aluminium alloy. One option is a dual alloy with an aluminium zinc alloy top-plating layer, if it is a sheet material; the second option is to anodise or powder-coat the aluminium.

The next step is to make certain that the proposed assembly is well detailed and the workmanship on site is of a high standard. Particular attention should be paid to ensuring the avoidance of bimetallic corrosion between dissimilar metals such as aluminium and copper. This topic has been well understood for many years; for example, British Standards PD 6484 – Commentary on corrosion at bimetallic contacts and its alleviation was published in 1979. Examples within Chapter Three *Aluminium Pioneers* show that the need to avoid bimetallic corrosion was understood by leading architects well before this date.

Fig 9.1 Weathering of aluminium alloys, from K. Barton (1976)



The science of the atmospheric oxidation and corrosion of aluminium appears to be well understood, except the composition of electrolyte layers.[2] Following initial oxidation and the formation of an ever-changing electrolyte layer, aluminium alloys progress to a stable state, when considered over a human timescale rather than a geological timeframe.[3] This research team recommends that the global aluminium fabrication industry should continue long-term exposure testing of aluminium.

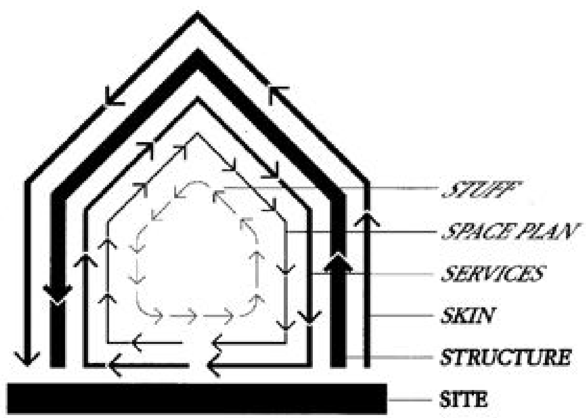
The location of a site and microclimatic considerations need to be taken into account. The order of risk of corrosion is rural, urban, industrial (highly polluted atmosphere) or coastal, with coastal plus industrial being the worst case. However, there are examples of cast aluminium proving very durable in highly polluted urban situations, such as the sculpture of Eros in London, and aluminium roof sheeting in a maritime/polluted context, such as the roof of the packing hall in Hamburg Docks. In Europe, since the tightening of controls on pollution, some consider the difference between rural, urban and industrial areas to now have less significance in terms of corrosion.[4] Clearly, however, this is not the case in developing countries, including China.

Aluminium is more durable when washed by rain and therefore, where possible, architects and engineers should detail buildings to facilitate the washing of the surface by rain. This contrasts with the traditions of masonry construction detailing. The aluminium should be detailed to avoid crevices where water can be trapped and remain for long periods, either by open-joint details such as a rainscreen cladding or sealing with a gasket or silicone seal.

A logical extension of this is to periodically wash the aluminium sections, whether these are cladding panels or window extrusions. The aluminium industry will provide up to 40-year guarantees for super-durable polyester powder coating; however, such guarantees are dependent on periodic cleaning.[5] Architects should design in cleaning and maintenance access, even if this is not yet part of their country's legislative framework. The need for regular cleaning does not appear to be well understood by building owners; however, there is evidence that major facilities management firms understand this, as do Private Finance Initiative [PFI] contractors, who have a contractual duty to maintain the project for the first 25 years of its life (and hopefully this will be continued after this somewhat arbitrary timeframe). It is clear that the stewardship of buildings and infrastructure is a key component of long-term sustainability. This research team recommends that the aluminium fabrication and finishing industries should produce a clear and concise guide to the necessity and benefits of cleaning aluminium components on buildings for both building owners and building managers.

A further recommendation based on this research is that design and construction details for aluminium building components should be reversible, either to facilitate refinishing, relocation and resuse or recycling in the long term. Thus, when the aluminium finish eventually needs recoating, or the building needs to be relocated or is no longer required, the components can be recoated or recycled without difficulty.

This research has revealed aluminium-based architecture that is performing well in our towns, cities and rural landscapes. The durability of this aluminium architecture should be recognised and celebrated. A key starting point for this research task was an apparently simple observation by the UK aluminium industry: 'There are probably 100s of examples of aluminium-based architecture that are fit but forgotten.'[6] This research establishes that aluminium-based architecture is fit but no longer forgotten – this excellence should be celebrated.



SHEARING LAYERS OF CHANGE. Because of the different rates of change of its components, a building is always tearing itself apart.

Fig 9.2 SHEARING LAYERS OF CHANGE, from *How Buildings Learn* by Stewart Brand (1994)

The interim conclusion of this research suggests that well-specified and well-detailed aluminium architecture should be considered to be very durable and have a very long life expectancy. In his 1994 book *How Buildings Learn*, Stewart Brand suggested that 'skins' will only last 20 years, basing this on a 1990 paper by Francis Duffy of the architectural practice DEGW, whereas Brookes and Stacey were writing about aluminium and durability in 1988.[7] Even in New York, the cycle for the replacement of curtain walling on major projects is about 50 years. The oldest extant aluminium components of architecture in this study are now 120 years old.[8]

The research team makes the following recommendations as regards life expectancy:

- Aluminium components within a maintained interior, such as a church or library, appear to have an infinite life expectancy.
- Aluminium components exposed to weather, including sun and rain, have a life expectancy of over 120 years.

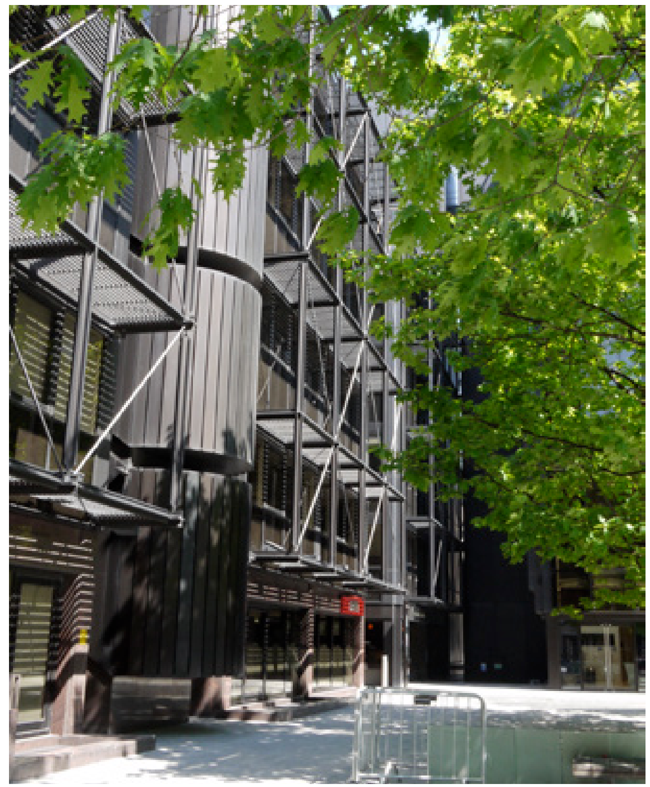


Fig 9.3 Bronze anodised curtain walling of 1 Finsbury Avenue, London, Arup Associates 1985

Based on the findings of this research, the service life of aluminium windows, used by organisations including Building Research Establishments, should be revised upwards from 40 years to at least 80 years. Site or programme specific issues, such as the use of aluminium within a swimming pool or an aggressive industrial interior, may limit these life expectancies; each factor needs to be carefully considered by architects and engineers. For polyester powder coating, the recoating method needs to be well specified. The oldest polyester powder coating still in service in this study is 42 years old and has not been recoated; the guarantees offered in 1973 were only ten years. The oldest example of PVDF-coated aluminium in this study is 27 years old and looks very similar in appearance to when it was first inspected by the author in 1988.[9]

Aluminium-based architecture has a very valuable role to play in the creation of sustainable cities, sustainable urban habitats for humankind.

Notes

1 As set out in this report, especially Chapters Three, Four and Seven.
2 G. Sowinski and D. O. Sprowls (1982), *Weathering of Aluminum Alloys*, Wiley, New York, pp. 297–328.
3 K. Barton (1976), *Protection against Atmospheric Corrosion: Theories and Methods*, Wiley, London.
4 A. Heyn (2009), BAM Expert opinion: Evaluation of Kalzip profiled sheet after long-term exposure at different locations, VI.1/14669, supplied by Kalzip to the author.
5 For more cleaning recommendations for specific locations, such as coastal sites, see p. 259. For guarantee periods including areas of high insolation, see pp. 273–274.
6 This discussion with the author commenced at Qualicoat and ESTEL Congress 27–28 October 2011, Munich, involving Mo Panam (Barley Chalu), Justin Ratcliffe (CAB) and Adrian Toon (FACET).
7 S. Brand (1994), *How Buildings Learn: What Happens After They're Built*, Viking Press, New York; F. Duffy (1990), *Measuring Building Performance*, Facilities, 8(5), pp. 17–21; A. Brookes and M. Stacey (1988), *Curtain Walling Product Review*, AJ Focus, Oct ober, pp. 31-55.
8 Age of the project on publication of the Second Edition of *Aluminium and Durability* in 2015.
9 Ibid.

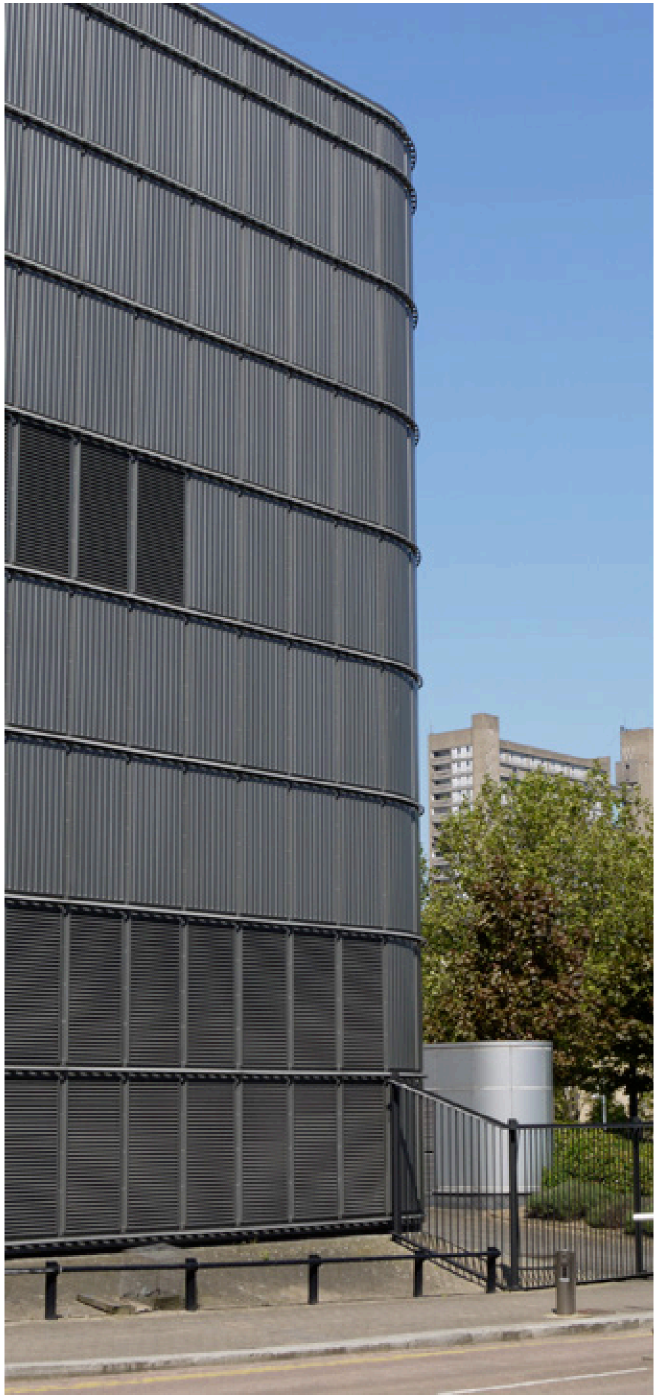


Fig 9.4 Financial Times Printworks, architect Nicholas Grimshaw & Partners, 1988: PVDF-coated aluminium cladding with silver anodised cladding rails

APPENDIX – A

exova testing results

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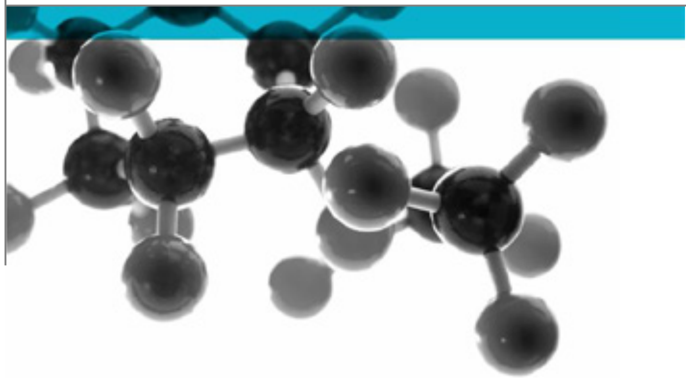
Testing of Aluminium Finishes on projects that are over 25 years old



Report To: **Michael Stacey Architects**
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Document Reference**: N965283**

Date: 11/2/14

Copy: 1

Issue No.: 1

Page 1

Testing
Advising
Assuring

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Client:	Michael Stacey Architects	Issue No.:	1

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Client:	Michael Stacey Architects	Issue No.:	1

Contents

1.0 **INTRODUCTION**

1.1. This report is concerned with the performance of 3 projects, these are listed below

Project 1
New Bodleian Library
University of Oxford
Broad Street
Oxford
OX1 3BG

Silver anodised aluminium windows.

Project 2
Herman Miller
Methuen Park
Chippenham,
Wiltshire
SN14 0GXA

Polyester powder coated pressed aluminium cladding rails and aluminium window frames.

Project 3
UBS Offices
1 Finsbury Avenue
City London
EC2M 2PA

Bronze anodised aluminium curtain walling and extruded aluminium cladding.

1.2. The projects are all over 25 years old from when they were constructed, or assembled.

New Bodleian Library windows are dated installed 1938 (75 years old).

Herman Miller was built 1983 (31 years old).

UBS London was built in 1985 (28 years old).

2.0 **TEST METHODS**

2.1. Colour based on ISO 7724-3 Paints and Varnishes – Colorimetry – Part 3: Calculation of colour differences using reference materials from site or storage to set the standard then reference points from different aspects of the buildings (20 readings on each aspect)

2.2. Gloss-based on the principles of BS EN ISO 2813 Paints and varnishes. Measurement of specular gloss of non-metallic paint films. The 60° angle was chosen, as this is used on most powder and anodised finishes.

2.3. ISO 4628-11:2011 Paints and varnishes -- Evaluation of degradation of coatings -- Designation of quantity and size of defects, and of intensity of uniform changes in appearance – Part 6: Assessment of degree of chalking by tape method. A length of adhesive tape is applied to the surface of the coating and then removed. Any loosely bound chalk will adhere to the tape and the quantity present is assessed by viewing the tape against a contrasting background and comparing it with a set of five photographs which are included in the standard. The sample is given the rating of the photograph that bears the closest resemblance.

2.4. BS EN ISO 2360: 2003 Non-conductive coatings on non-magnetic electrically conductive basis materials – Measurement of coating thickness – Amplitude-sensitive eddy current method.

3.0 TESTING

3.1. Testing was done at ground level as the buildings are several metres tall, and would have incurred several Health & Safety issues with working at heights etc.

3.2. Drawings were made by Ben Stanforth, and have been included in this report to show the areas where testing was carried out.

3.3. Testing carried out on the powder coated finished aluminium, which was mainly residual colour, film thickness & gloss, though measuring the colour of the T-bar was not possible, so other parts were used if possible but not ideal, due to being of a different orientation on the facades.

3.4. Testing of the anodised finished was residual colour and film thickness on the Bronze anodised finished building, and just residual film thickness on the Natural anodised finished windows.

4.0 TEST EQUIPMENT

4.1. BYK Gloss meter
X-rite colour measuring (Hand held).
Elcometer 456 FNF film thickness measuring gauge, fitted with a type 1 FNF probe.

FNF = Dual substrate. Measures film thickness's on both aluminium and steel substrates.

4.2. The key for the colour differences are as follows.

L	A	B	E
+ = Lighter	+ = Redder	+ = Yellower	Indicates how much the colour deviates from standard
- = Darker	- = Greener	- = Bluer	

The Delta E value is calculated using the following equation:

$$\Delta E = \sqrt{L^2 + A^2 + B^2}$$

5.0 CONSOLIDATED TEST RESULTS – UBS Building - London

5.1. Test results for the Bronze Anodised finish – Colour and film thickness.

Std extrusion

L	A	B	E	Ave FT
29.77	2.57	4.10	30.16	24.3

①

L	A	B	E	FT Var
-1.82	-0.64	-1.21	2.28	-1.1

②

L	A	B	E	FT Var
-4.17	-2.57	-3.76	6.17	0.4

③

L	A	B	E	FT Var
-1.83	-0.28	-0.62	1.95	2.4

④

L	A	B	E	FT Var
-0.07	0.50	1.70	1.78	-2.1

⑤

L	A	B	E	FT Var
-1.19	0.40	1.29	1.80	-2.0

⑥

L	A	B	E	FT Var
-2.48	-0.01	0.10	2.48	-3.2

⑦

L	A	B	E	FT Var
-1.31	-0.23	0.22	1.35	2.2

⑧

L	A	B	E
-1.59	-0.34	-0.41	1.68

FT Var
-4.1

⑨

L	A	B	E
0.49	0.73	2.22	2.39

FT Var
-1.8

⑩

L	A	B	E
-0.69	-0.47	-1.02	1.32

FT Var
0.1

⑪

L	A	B	E
0.01	0.24	1.32	1.34

FT Var
-3.3

⑫

L	A	B	E
-1.01	-0.18	-0.64	1.21

FT Var
-1.9

⑬

L	A	B	E
-0.05	0.21	1.02	1.04

FT Var
4.5

⑭

L	A	B	E
1.03	-0.70	0.45	1.32

FT Var
1.1

6.0 CONSOLIDATED TEST RESULTS – New Bodleian Library

6.1. The windows had the residual FT checked. The first window checked on the exterior has been used as the standard.

①

1st Window - Exterior (STD)

Max	30.0
Min	20.6
Average	25.4
SD	3.21

②

Max	24.8
Min	9.2
Average	15.3
SD	4.38

③

Max	21.6
Min	8.0
Average	14.8
SD	4.99

④

Max	18.9
Min	10.9
Average	13.6
SD	2.48

⑤

Max	22.0
Min	11.9
Average	15.5
SD	3.30

⑥

Max	17.0
Min	7.1
Average	10.7
SD	2.75

⑦

Max	18.3
Min	7.6
Average	12.1
SD	3.77

⑧

Max	15.5
Min	10.6
Average	13.4
SD	1.51

⑨

Max	13.8
Min	8.4
Average	11.7
SD	1.58

⑩

Max	19.6
Min	8.4
Average	15.3
SD	3.07

⑪

Max	18.3
Min	7.4
Average	12.9
SD	3.44

⑫ Window inside - Top floors - Site Office

Max	16.5
Min	11.0
Average	14.8
SD	1.72

7.0 **CONSOLIDATED TES RESULTS – Herman Miller - Chippenham**

7.1. Light Blue Panels (RAL 5012) – Colour, Gloss & Film Thickness

1 Front Aspect Colour
Panels (Light Blue)

L	A	B	E	Gloss Var	FT Var
-1.10	-1.19	-0.92	1.86	-16.47	10.15

Side aspect West. (protected behind POD) Panel Light Blue

L	A	B	E		Gloss	FT
58.09	-14.33	-31.92	67.81	**Used as STD**	54.07	56.67

6 South west façade.
Light blue panel.

L	A	B	E	Gloss Var	FT Var
-1.24	-1.58	-1.00	2.24	-34.55	5.27

7 South façade
Light blue panel.

L	A	B	E	Gloss Var	FT Var
-1.40	-1.79	-0.26	2.29	-43.33	1.99

9 East façade. B&Q side
Light blue panels

L	A	B	E	Gloss Var	FT Var
-1.68	-1.46	-1.21	2.53	-35.92	1.55

10 East façade B&Q
Light blue panels

L	A	B	E	Gloss Var	FT Var
-1.26	-1.45	-0.84	2.10	-39.17	-2.82

11 Front Aspect
Light blue cladding panel

L	A	B	E	Gloss Var	FT Var
-1.60	-1.42	-1.30	2.50	-23.03	2.72

12 Front aspect test 3

Light blue panel

L	A	B	E	Gloss Var	FT Var
-0.42	1.02	6.21	6.31	-46.2	3.61

13 South façade. Test 2

Light blue panel

L	A	B	E	Gloss Var	FT Var
-1.23	-1.91	-1.04	2.50	-45.8	-4.89

1.1. Dark Blue Panels (RAL 5010) – Colour, Gloss & Film Thickness

2 POD

Panels (Dark Blue)

L	A	B	E	Gloss Var
0.21	-1.53	-2.26	2.74	-68.80

4 POD 2 (protected) West

Panels (Dark Blue)

L	A	B	E		Av Gloss
38.46	-5.54	-26.89	47.25	**Used as STD**	75.90

5 POD 2 dark blue panel exposed

L	A	B	E	Gloss Var
0.42	-1.60	-2.45	2.96	-69.02

8 POD 3 South

Panels (Dark Blue)

L	A	B	E	Gloss Var
0.62	-1.62	-2.16	2.77	-67.23

1.2. Cobalt Blue T-bar (RAL 5003) (Gloss & FT) window panel for colour – Colour, Gloss & Film Thickness

1 Front Aspect Colour (Cobalt)

L	A	B	E	Gloss Var	FT Var
-0.67	-0.04	-1.48	1.63	-54.97	-51.08

Cobalt

L	A	B	E	Gloss		FT
Cannot measure T-bar				62.60	**Used as STD Gloss & FT**	143.30

4 POD 2 (protected) West

Cobalt

L	A	B	E	Gloss Var	FT Var
Cannot measure T-bar				-2.60	21.40

5 POD 2 West. Exposed, Cobalt cover used for colour test

Cobalt

L	A	B	E	Gloss Var	FT Var
-0.11	-0.09	33.53	33.53	-53.65	-37.68

8 POD 3 South

Cobalt cover for colour

L	A	B	E		Gloss	FT
33.01	-2.27	-16.28	36.88	**Used as STD Colour**	-49.10	-43.13

10 East façade B&Q

Cobalt

L	A	B	E	Gloss Var	FT Var
-0.06	-0.01	-0.80	0.81	-54.55	-51.99

11 Front Aspect

Cobalt window for colour

L	A	B	E	Gloss Var	FT Var
0.50	-0.06	-0.70	0.86	-44.43	47.70

12 Front aspect test 3

Cobalt

L	A	B	E	Gloss Var	FT Var
Cannot measure T-bar				-55.35	-20.47

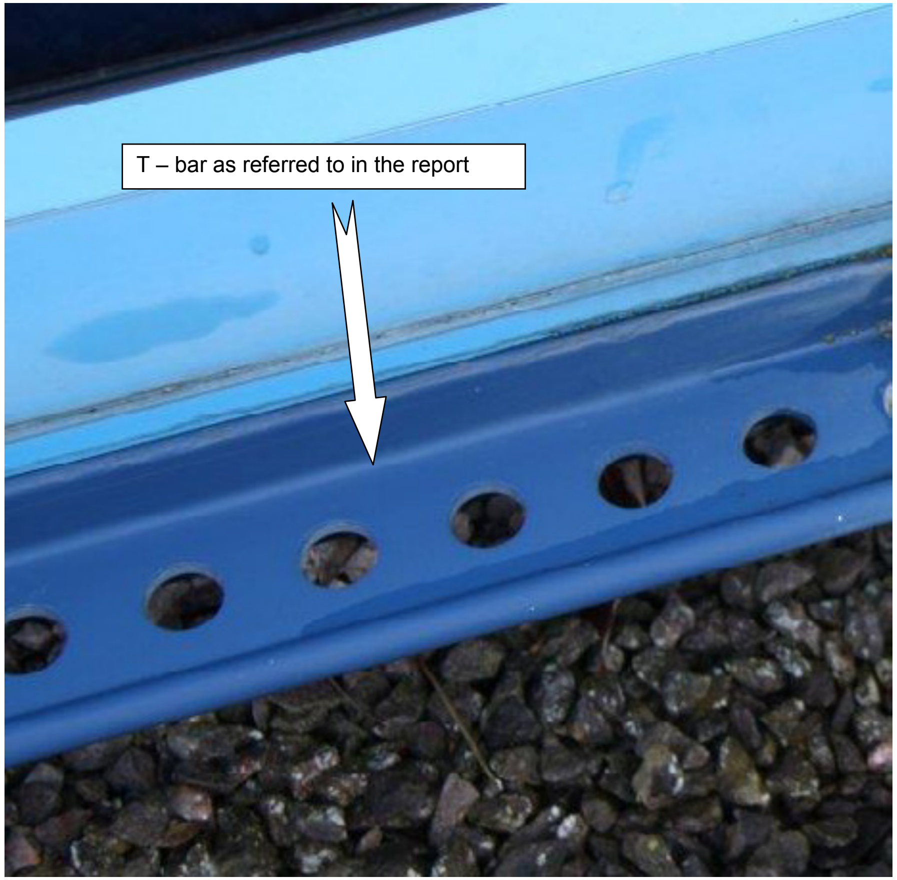
13 South façade. Test 2

Cobalt

L	A	B	E	Gloss Var	FT Var
2.40	0.23	0.84	2.55	-57.88	-81.31

1.3. T-bar definition

The T-bar on the Herman Miller is shown on the picture below. The bar with holes in is referred to as the T-bar.



8.0 **OBSERVATIONS**

8.1. UBS Building – London

Certain extrusions did show signs of colour difference. This is where the extruded anodised sections had turned bluer.

Another effect noticed on the anodised extruded aluminium. Where it had been under cover, the surface had become rough and not as sooth to the touch where it had been exposed to weathering.

The film thickness of the anodised layer was very uniform over all the anodised sections measured.

8.2. New Bodleian Library – Oxford

The film thickness of the anodised layer, was variable over most of the window frames measured, this is dependent on the original specification the product was anodised to.

8.3. Herman Miller – Chippenham

It was obvious from looking at the building, that there hadn't been much exterior maintenance of the facades. This can be confirmed from the areas of the pale blue that had to be cleaned to check the colour of the powder coating.

There was another phenomenon noticed on the façade panels, "Filiform corrosion". Although it wasn't obvious in the beginning, but there were areas on the side near B&Q, where it was quite clear to see this effect. Pictures are in this report, with a ruler to see the length & width of this type of surface corrosion.

The results contained within this report have been reported in an abbreviated format. The test data and result sheets containing more detailed information in accordance with the technical works procedures or standards used are held at Exova as part of the accredited quality assurance system. Opinions and interpretations expressed herein are outside the scope of the UKAS accreditation of this laboratory.

END OF TEXT – Figures attached

Report Signatories

Author	Geoffrey Addicott  (For and on behalf of Exova (UK) Ltd)
Approver	(Insert Signature) (For and on behalf of Exova (UK) Ltd)

Appendices

Figure 1; Colour, Gloss and film thickness measurements.(Herman Miller, Chippenham)

1 Front Aspect Colour (Cobalt – RAL 5003)

	L	a	b	E
	32.26	-2.25	-17.75	36.89
	32.40	-2.25	-17.83	37.05
	32.45	-2.53	-17.84	37.12
	32.31	-2.23	-17.67	36.89
	32.28	-2.28	-17.74	36.90
Av	32.34	-2.31	-17.77	36.97

	Gloss 60° T-bar
	4.50
	6.80
	7.30
	8.40
	8.90
	9.90
Ave	7.63

FT's	
104.0	87.4
93.6	88.3
79.7	73.6
91.8	109.0
89.8	105.0
Av	92.2
Min	73.6
Max	109.0
Sdev	11.22

Panels (Light Blue – RAL 5012)

	L	a	b	E
	56.68	-15.33	-32.55	67.14
	57.13	-15.49	-32.85	67.70
	57.06	-15.45	-32.76	67.59
	57.05	-15.64	-33.03	67.75
	57.02	-15.70	-33.00	67.73
Av	56.99	-15.52	-32.84	67.58

Gloss 60°
37.20
39.10
37.30
40.40
32.50
39.10
37.60

FT's	
69.8	66.5
67.2	64.8
61.5	70.6
69.9	66.2
64.3	67.4
Av	66.8
Min	61.5
Max	70.6
Sdev	2.84

2 POD

Cobalt – RAL 5003

	L	a	b	E
	33.06	-2.62	-17.44	37.47
	33.18	-2.71	-17.53	37.62
	33.03	-2.78	-17.72	37.59
	33.07	-2.64	-17.25	37.39
	33.23	-2.85	-17.82	37.81
Av	33.11	-2.72	-17.55	37.58

Gloss 60°
21.20
22.10
17.70
16.10
15.10
14.70
17.82

FT's	
149.0	115.0
133.0	102.0
125.0	101.0
130.0	103.0
112.0	103.0
Av	117.3
Min	101.0
Max	149.0
Sdev	16.38

Panels (Dark Blue – RAL 5010)

	L	a	b	E
	38.77	-7.01	-29.08	48.97
	38.81	-7.13	-29.35	49.18
	37.96	-7.10	-29.18	48.40
	39.01	-7.03	-29.10	49.17
	38.79	-7.07	-29.06	48.98
Av	38.67	-7.07	-29.15	48.94

Gloss 60°
6.60
7.40
6.60
6.70
7.10
8.20
7.10

FT's	
98.8	98.2
97.7	97.8
95.4	101.0
95.1	95.3
95.9	95.1
Av	97.0
Min	95.1
Max	101.0
Sdev	1.99

3 Side aspect West. (protected behind POD) Panel Light Blue

Cobalt

	L	a	b	E
	65.45	-14.29	-31.42	73.99
	56.12	-14.40	-32.19	66.28
	56.36	-14.25	-31.82	66.27
	56.27	-14.40	-32.05	66.34
	56.23	-14.33	-32.12	66.32
Av	58.09	-14.33	-31.92	67.81

Gloss 60°
57.40
53.40
52.10
58.10
49.60
53.80
54.07

FT's	
61.4	55.8
56.2	56.8
54.5	58.6
57.1	53.4
58.4	54.5
Av	56.7
Min	53.4
Max	61.4
Sdev	2.37

Cobalt

L a b E

Colour not done

Av

Gloss 60°
66.20
58.20
53.40
62,8
67.20
68.00
62.60

FT's	
118.0	137.0
158.0	122.0
177.0	127.0
186.0	136.0
146.0	126.0
Av	143.3
Min	118.0
Max	186.0
Sdev	23.41

4 POD 2 (protected) West

Cobalt – RAL 5003

L a b E

Colour not done

Av

Gloss 60°
60.70
63.70
61.90
60.80
59.90
53.00
60.00

FT's	
192.0	152.0
188.0	140.0
206.0	154.0
163.0	154.0
151.0	147.0
Av	164.7
Min	140.0
Max	206.0
Sdev	22.36

Panels (Dark Blue – RAL 5010)

	L	a	b	E
	38.26	-5.86	-27.93	47.73
	39.04	-5.58	-26.23	47.36
	39.01	-5.26	-27.41	47.97
	38.58	-5.65	-26.06	46.90
	37.41	-5.36	-26.82	46.34
Av	38.46	-5.54	-26.89	47.25

Gloss 60°
67.40
75.50
78.10
77.40
79.00
78.00
75.90

FT's	
117.0	109.0
110.0	112.0
110.0	114.0
109.0	111.0
110.0	103.0
Av	110.5
Min	103.0
Max	117.0
Sdev	3.63

5 POD 2 West. Exposed, Cobalt cover used for colour test

Cobalt – RAL 5003

	L	a	b	E
	32.94	-2.54	17.29	37.29
	32.81	-2.40	17.33	37.18
	32.88	-2.23	17.29	37.22
	33.01	-2.33	17.11	37.25
	32.88	-2.28	17.20	37.18
Av	32.90	-2.36	17.24	37.22

Gloss 60° T-bar
8.00
10.90
10.10
8.60
7.90
8.20
8.95

FT's	
125.0	88.1
132.0	87.3
120.0	95.3
105.0	101.0
91.5	111.0
Av	105.6
Min	87.3
Max	132.0
Sdev	15.91

POD 2 dark blue panel exposed – RAL 5010

	L	a	b	E
	39.14	-7.17	-29.47	49.52
	38.38	-7.16	-29.33	48.83
	38.97	-7.04	-29.13	49.16
	38.95	-7.17	-29.46	49.36
	38.97	-7.19	-29.33	49.30
Av	38.88	-7.15	-29.34	49.23

Gloss 60°
7.30
7.80
8.10
7.10
5.40
5.60
6.88

FT's	
40.5	44.6
36.7	46.3
40.3	50.4
46.2	49.0
40.6	46.9
Av	44.2
Min	36.7
Max	50.4
Sdev	4.41

6 South west façade.

Cobalt cover for colour – RAL 5003

L a b E

Colour not done

Av

Gloss 60°
7.90
7.70
7.60
8.50
8.40
8.70
8.13

FT's	
99.5	110.0
85.8	122.0
106.0	106.0
112.0	96.8
121.0	101.0
Av	106.0
Min	85.8
Max	122.0
Sdev	11.02

Light blue panel – RAL 5012

	L	a	b	E
	56.65	-16.06	-33.07	67.53
	56.75	-16.07	-33.00	67.59
	56.97	-15.84	-32.90	67.67
	57.04	-15.83	-32.90	67.72
	56.84	-15.78	-32.72	67.46
Av	56.85	-15.92	-32.92	67.59

Gloss 60°
17.40
19.50
20.80
20.70
21.90
16.80
19.52

FT's	
75.1	56.9
67.0	57.3
63.4	53.7
66.4	53.5
74.7	51.4
Av	61.9
Min	51.4
Max	75.1
Sdev	8.70

7 South façade

Cobalt window for colour – RAL 5003

	L	a	b	E
	33.10	-2.19	-16.84	37.20
	33.16	-2.06	-16.05	36.90
	33.00	-2.08	-16.66	37.03
	32.89	-2.05	-16.53	36.87
	33.24	-2.09	-16.80	37.30
Av	33.08	-2.09	-16.58	37.06

Gloss 60°
5.20
4.50
6.10
5.30
7.00
10.40
6.42

FT's	
60.7	61.9
92.3	69.6
69.9	75.2
57.1	70.0
55.8	69.2
Av	68.2
Min	55.8
Max	92.3
Sdev	10.60

Light blue panel.

	L	a	b	E
	57.25	-16.23	-32.21	67.66
	56.59	-16.13	-32.18	67.07
	56.65	-16.12	-32.24	67.15
	56.70	-16.08	-32.27	67.19
	56.25	-16.06	-31.99	66.67
Av	56.69	-16.12	-32.18	67.15

Gloss 60°
10.10
8.30
16.00
9.10
10.60
10.30
10.73

FT's	
58.8	57.7
57.7	60.5
56.3	64.2
56.0	60.7
53.4	61.3
Av	58.7
Min	53.4
Max	64.2
Sdev	3.12

8 POD 3 South

Cobalt cover for colour – RAL 5003

	L	a	b	E
	33.13	-2.23	-16.09	36.90
	32.72	-2.35	-16.62	36.77
	32.48	-2.33	-16.81	36.65
	33.70	-2.18	-15.68	37.23
	33.04	-2.24	-16.22	36.87
Av	33.01	-2.27	-16.28	36.88

Gloss 60° T-bar
11.20
13.80
14.20
13.20
13.30
15.30
13.50

FT's	
74.6	104.0
107.0	102.0
115.0	87.9
108.0	96.0
110.0	97.2
Av	100.2
Min	74.6
Max	115.0
Sdev	11.89

Panels (Dark Blue – RAL 5010)

	L	a	b	E
	38.85	-7.36	-29.35	49.24
	39.13	-7.09	-28.97	49.20
	39.37	-7.05	-28.82	49.30
	39.10	-7.15	-29.06	49.24
	38.93	-7.17	-29.04	49.09
Av	39.08	-7.16	-29.05	49.21

Gloss 60°
7.70
9.40
10.10
9.00
7.60
8.20
8.67

FT's	
97.3	86.8
82.2	89.1
84.5	91.1
88.4	97.0
88.4	99.8
Av	90.5
Min	82.2
Max	99.8
Sdev	5.82

9 East façade. B&Q side

Cobalt window for colour – RAL 5003

	L	a	b	E
	32.88	-2.09	-16.72	36.95
	32.91	-2.20	-17.03	37.12
	32.75	-2.25	-17.09	37.01
	32.75	-2.26	-17.19	37.06
	32.73	-2.24	-17.16	37.02
Av	32.80	-2.21	-17.04	37.03

Gloss 60°
9.00
7.60
7.40
6.80
7.40
7.90
7.68

FT's	
103.0	109.0
134.0	95.5
129.0	89.9
120.0	95.6
124.0	112.0
Av	111.2
Min	89.9
Max	134.0
Sdev	15.25

Light blue panels – RAL 5012

	L	a	b	E
	56.21	-15.56	-32.83	66.93
	56.43	-15.69	-33.17	67.31
	56.33	-15.89	-33.23	67.30
	56.61	-15.91	-33.21	67.53
	56.46	-15.92	-33.19	67.40
Av	56.41	-15.79	-33.13	67.30

Gloss 60°
26.10
24.40
15.60
14.30
14.50
14.00
18.15

FT's	
61.9	53.3
61.6	55.8
60.8	57.1
58.3	62.1
54.9	56.4
Av	58.2
Min	53.3
Max	62.1
Sdev	3.20

10 East façade B&Q

Cobalt – RAL 5003

	L	a	b	E
	33.02	-2.25	-16.90	37.16
	33.06	-2.26	-17.07	37.28
	32.84	-2.28	-17.19	37.14
	32.85	-2.31	-17.19	37.15
	33.02	-2.28	-17.09	37.25
Av	32.96	-2.28	-17.09	37.19

Gloss 60°
4.40
13.90
7.60
7.10
6.80
8.50
8.05

FT's	
112.0	80.7
102.0	88.1
99.4	89.8
98.7	75.3
88.5	78.6
Av	91.3
Min	75.3
Max	112.0
Sdev	11.61

Light blue panels – RAL 5012

	L	a	b	E
	56.74	-15.86	-32.86	67.46
	56.79	-15.85	-32.86	67.50
	56.74	-15.72	-32.76	67.38
	56.97	-15.74	-32.61	67.50
	56.89	-15.75	-32.71	67.49
Av	56.83	-15.78	-32.76	67.47

Gloss 60°
14.40
16.10
14.80
15.60
14.90
13.60
14.90

FT's	
65.2	53.0
56.6	52.9
56.9	46.2
53.2	50.2
51.6	52.7
Av	53.9
Min	46.2
Max	65.2
Sdev	5.01

11 Front Aspect

Cobalt window for colour – RAL 5003

	L	a	b	E
	33.64	-2.27	-16.92	37.72
	33.47	-2.34	-17.01	37.62
	33.55	-2.37	-17.04	37.70
	33.49	-2.34	-16.98	37.62
	33.42	-2.33	-16.97	37.55
Av	33.51	-2.33	-16.98	37.64

Gloss 60° T-bar
19.70
21.10
21.60
18.70
14.90
13.00
18.17

FT's	
159.0	198.0
202.0	171.0
242.0	154.0
253.0	147.0
223.0	161.0
Av	191.0
Min	147.0
Max	253.0
Sdev	38.40

Light blue cladding panel – RAL 5012

	L	a	b	E
	56.41	-15.77	-33.23	67.34
	56.54	-15.66	-32.95	67.29
	56.48	-15.75	-33.26	67.41
	56.56	-15.74	-33.12	67.41
	56.44	-15.83	-33.55	67.54
Av	56.49	-15.75	-33.22	67.40

Gloss 60°
32.00
34.70
29.90
28.80
29.50
31.30
31.03

FT's	
63.0	59.8
59.8	57.7
61.6	60.4
58.7	57.0
59.7	56.2
Av	59.4
Min	56.2
Max	63.0
Sdev	2.07

12 Front aspect test 3

Cobalt – RAL 5003

	L	a	b	E
	Colour not done			
Av				

Gloss 60°
4.50
5.60
8.70
7.00
8.60
9.10
7.25

FT's	
131.0	125.0
122.0	121.0
112.0	152.0
97.3	140.0
112.0	116.0
Av	122.8
Min	97.3
Max	152.0
Sdev	15.47

Light blue panel

Light blue panel – RAL 5012

	L	a	b	E
	57.51	-14.90	-29.72	66.43
	59.06	-13.66	-27.04	66.38
	56.72	-12.43	-23.21	62.53
	56.78	-12.51	-23.56	62.73
	58.24	-13.06	-25.02	64.72
Av	57.66	-13.31	-25.71	64.52

Gloss 60°
11.30
7.80
7.80
6.60
6.60
7.10
7.87

FT's	
71.4	61.0
63.7	55.6
63.3	54.6
63.1	45.3
65.1	59.7
Av	60.3
Min	45.3
Max	71.4
Sdev	7.11

13 South façade. Test 2

Cobalt – RAL 5003

	L	a	b	E
	34.91	-2.13	-15.78	38.37
	34.83	-2.05	-15.92	38.35
	35.63	-1.99	-15.27	38.82
	35.99	-1.99	-15.14	39.10
	35.71	-2.03	-15.11	38.83
Av	35.41	-2.04	-15.44	38.69

Gloss 60°
4.40
4.40
4.30
4.20
5.60
5.40
4.72

FT's	
68.2	59.7
88.5	47.5
76.9	53.4
74.5	46.5
60.1	44.6
Av	62.0
Min	44.6
Max	88.5
Sdev	14.74

Light blue panel

Light blue panel – RAL 5012

	L	a	b	E
	56.87	-16.21	-32.86	67.65
	56.87	-16.27	-33.03	67.75
	56.91	-16.27	-33.03	67.78
	56.72	-16.23	-32.90	67.55
	56.89	-16.22	-32.97	67.72
Av	56.85	-16.24	-32.96	67.69

Gloss 60°
7.20
7.30
8.60
7.90
9.50
8.90
8.23

FT's	
47.8	48.8
60.1	51.4
43.2	58.1
49.2	50.1
50.3	58.8
Av	51.8
Min	43.2
Max	60.1
Sdev	5.46

Figure 2; Film thickness measurements (New Bodleian Library, Oxford)

Film thickness's

①

1	27.2
2	20.6
3	21.1
4	25.6
5	29.2
6	30.0
7	24.0
8	26.8
9	26.5
10	22.7

Max	30.0
Min	20.6
Average	25.4
SD	3.21

②

1	14.3
2	17.6
3	17.0
4	16.9
5	15.3
6	24.8
7	14.9
8	10.8
9	9.2
10	11.7

Max	24.8
Min	9.2
Average	15.3
SD	4.38

③

1	14.8
2	8.4
3	15.2
4	20.9
5	10.8
6	8.0
7	16.9
8	21.6
9	19.6
10	11.7

Max	21.6
Min	8.0
Average	14.8
SD	4.99

④

1	16.4
2	18.9
3	13.0
4	10.9
5	11.3
6	13.1
7	12.7
8	13.3
9	14.6
10	11.5

Max	18.9
Min	10.9
Average	13.6
SD	2.48

⑤

1	11.9
2	14.6
3	19.7
4	22.0
5	12.7
6	14.4
7	15.2
8	17.6
9	12.7
10	13.7

Max	22.0
Min	11.9
Average	15.5
SD	3.30

⑥

1	11.2
2	10.1
3	9.9
4	8.9
5	9.6
6	8.7
7	12.9
8	17.0
9	7.1
10	11.6

Max	17.0
Min	7.1
Average	10.7
SD	2.75

⑦

1	7.6
2	11.9
3	11.8
4	8.5
5	10.9
6	13.9
7	17.8
8	12.8
9	18.3
10	7.8

Max	18.3
Min	7.6
Average	12.1
SD	3.77

⑧

1	12.6
2	12.1
3	14.6
4	14.5
5	13.3
6	14.0
7	15.5
8	14.8
9	10.6
10	12.4

Max	15.5
Min	10.6
Average	13.4
SD	1.51

⑨

1	11.8
2	10.9
3	8.4
4	11.4
5	12.7
6	13.8
7	10.8
8	11.0
9	13.3
10	13.0

Max	13.8
Min	8.4
Average	11.7
SD	1.58

⑩

1	15.6
2	19.2
3	8.4
4	14.9
5	14.8
6	16.3
7	19.6
8	14.2
9	15.2
10	14.4

Max	19.6
Min	8.4
Average	15.3
SD	3.07

⑪

1	10.6
2	11.2
3	7.4
4	13.5
5	13.8
6	15.4
7	18.3
8	9.7
9	17.3
10	11.5

Max	18.3
Min	7.4
Average	12.9
SD	3.44

⑫ Window inside - Top floors - Site Office

1	16.0
2	11.0
3	15.0
4	15.0
5	16.5
6	15.7
7	15.7
8	12.8
9	14.2
10	16.1

Max	16.5
Min	11.0
Average	14.8
SD	1.72

Figure 3; Colour & film thickness measurements (UBS, London)

Film thickness's

Std extrusion

1	25.8
2	23.3
3	23.9
4	26.0
5	25.4
6	24.9
7	22.8
8	21.6
9	24.3
10	25.4

Max	26.0
Min	21.6
Average	24.3
SD	1.44

	L	a	b	E
	29.66	2.44	3.78	30.00
	29.87	2.51	3.95	30.23
	28.93	2.70	4.25	29.36
	30.25	2.60	4.25	30.66
	30.13	2.62	4.25	30.54
Av	29.77	2.57	4.10	30.16

①

1	21.1
2	21.7
3	22.7
4	23.4
5	22.6
6	22.9
7	24.0
8	23.3
9	24.8
10	25.7

Max	25.7
Min	21.1
Average	23.2
SD	1.37

	L	a	b	E
	28.01	1.96	2.89	28.23
	28.03	1.85	2.68	28.22
	28.07	1.98	3.06	28.31
	27.94	2.03	3.15	28.19
	27.71	1.85	2.64	27.90
Av	27.95	1.93	2.88	28.17

②

1	24.0
2	25.5
3	24.1
4	25.4
5	24.1
6	25.2
7	25.2
8	25.9
9	24.2
10	24.2

Max	25.9
Min	24.0
Average	24.8
SD	0.72

	L	a	b	E
	25.08	0.10	0.18	25.08
	24.65	0.15	0.33	24.65
	24.43	-0.05	0.12	24.43
	27.02	-0.07	0.72	27.03
	26.79	-0.09	0.35	26.79
Av	25.59	0.01	0.34	25.60

③ Window

1	29.2
2	29.6
3	29.8
4	27.1
5	25.5
6	24.0
7	24.8
8	26.8
9	25.2
10	25.8

Max	29.8
Min	24.0
Average	26.8
SD	2.10

	L	a	b	E
	27.72	2.08	3.13	27.97
	28.00	2.31	3.46	28.31
	28.10	2.44	3.77	28.46
	27.88	2.36	3.50	28.20
	28.01	2.29	3.53	28.32
Av	27.94	2.30	3.48	28.25

④ Window

1	21.3
2	22.8
3	24.7
4	22.1
5	22.8
6	21.5
7	22.4
8	21.7
9	22.3
10	20.4

Max	24.7
Min	20.4
Average	22.2
SD	1.15

	L	a	b	E
	29.43	3.10	5.64	30.13
	29.84	3.08	5.89	30.57
	29.68	3.19	6.15	30.48
	30.12	2.96	5.51	30.76
	29.41	3.06	5.81	30.13
Av	29.70	3.08	5.80	30.41

⑤

1	21.4
2	21.4
3	23.1
4	22.4
5	22.5
6	22.7
7	21.8
8	22.9
9	21.9
10	23.5

Max	23.5
Min	21.4
Average	22.4
SD	0.72

	L	a	b	E
	28.22	2.74	4.99	28.79
	28.12	2.70	4.88	28.67
	28.68	3.12	5.69	29.40
	29.09	3.22	5.78	29.83
	28.78	3.11	5.57	29.48
Av	28.58	2.98	5.38	29.23

⑥

1	29.7
2	21.3
3	18.7
4	20.8
5	21.7
6	20.4
7	19.0
8	21.3
9	19.8
10	19.0

Max	29.7
Min	18.7
Average	21.2
SD	3.18

	L	a	b	E
	27.01	2.43	3.94	27.40
	27.37	2.58	4.20	27.81
	27.48	2.80	4.74	28.03
	27.61	2.65	4.40	28.08
	26.96	2.34	3.70	27.31
Av	27.29	2.56	4.20	27.73

⑦ Under cover

1	31.0
2	30.0
3	23.6
4	28.0
5	28.6
6	26.3
7	24.8
8	21.7
9	25.4
10	26.3

Max	31.0
Min	21.7
Average	26.6
SD	2.88

	L	a	b	E
	29.00	2.43	4.62	29.47
	28.99	2.66	4.89	29.52
	28.54	2.53	4.61	29.02
	27.74	2.21	4.12	28.13
	28.00	1.87	3.33	28.26
Av	28.45	2.34	4.31	28.87

⑧

1	17.5
2	15.8
3	18.3
4	19.9
5	20.1
6	20.2
7	22.9
8	25.6
9	21.8
10	20.4

Max	25.6
Min	15.8
Average	20.3
SD	2.78

	L	a	b	E
	27.90	2.21	3.61	28.22
	27.77	2.18	3.56	28.08
	27.89	2.30	3.80	28.24
	28.60	2.18	3.65	28.91
	28.74	2.28	3.80	29.08
Av	28.18	2.23	3.68	28.51

⑨ Stairs

1	21.1
2	21.5
3	23.5
4	21.4
5	22.1
6	22.0
7	21.0
8	25.5
9	24.1
10	23.4

Max	25.5
Min	21.0
Average	22.6
SD	1.50

	L	a	b	E
	29.16	2.85	5.19	29.76
	29.94	3.31	6.30	30.77
	30.57	3.48	6.84	31.52
	31.01	3.45	6.72	31.92
	30.61	3.45	6.53	31.49
Av	30.26	3.31	6.32	31.09

⑩

1	23.6
2	23.1
3	22.0
4	24.9
5	27.3
6	24.9
7	26.5
8	25.0
9	25.3
10	21.5

Max	27.3
Min	21.5
Average	24.4
SD	1.86

	L	a	b	E
	29.24	2.02	2.87	29.45
	29.34	2.21	3.32	29.61
	28.97	2.13	3.18	29.22
	28.98	2.09	3.07	29.22
	28.85	2.08	2.95	29.07
Av	29.08	2.11	3.08	29.31

⑪ Window

1	20.2
2	20.5
3	19.4
4	21.6
5	22.0
6	22.3
7	20.5
8	21.2
9	21.1
10	21.3

Max	22.3
Min	19.4
Average	21.0
SD	0.87

	L	a	b	E
	30.00	2.87	5.83	30.70
	29.18	3.13	5.94	29.94
	30.23	2.81	5.41	30.84
	30.12	2.78	5.34	30.72
	29.37	2.50	4.55	29.83
Av	29.78	2.82	5.41	30.40

⑫

1	21.0
2	22.8
3	22.2
4	22.8
5	23.1
6	22.7
7	22.9
8	22.2
9	21.4
10	23.0

Max	23.1
Min	21.0
Average	22.4
SD	0.71

	L	a	b	E
	28.64	2.25	3.14	28.90
	28.71	2.35	3.26	28.99
	28.98	2.49	3.60	29.31
	28.58	2.45	3.61	28.91
	28.90	2.43	3.65	29.23
Av	28.76	2.39	3.45	29.07

⑬

1	21.2
2	24.8
3	32.5
4	28.2
5	26.7
6	29.4
7	29.2
8	33.0
9	31.3
10	31.7

Max	33.0
Min	21.2
Average	28.8
SD	3.73

	L	a	b	E
	29.68	2.73	4.77	30.18
	29.80	2.78	4.95	30.34
	29.75	2.85	5.90	30.46
	29.69	2.78	4.94	30.23
	29.68	2.80	5.01	30.23
Av	29.72	2.79	5.11	30.29

⑭

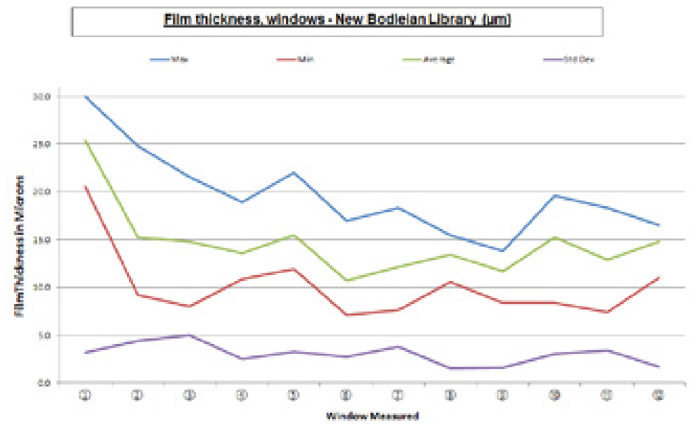
1	30.2
2	19.1
3	28.7
4	37.4
5	27.0
6	21.6
7	22.4
8	22.7
9	22.6
10	22.3

Max	37.4
Min	19.1
Average	25.4
SD	5.46

	L	a	b	E
	31.37	1.90	4.77	31.79
	30.84	1.68	4.43	31.20
	30.20	1.89	4.36	30.57
	31.07	1.96	4.94	31.52
	30.52	1.96	4.23	30.87
Av	30.80	1.88	4.55	31.19

Graph for New Bodleian Library Oxford

Figure 4; Graph of film thickness measurements - New Bodleian Library



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Graphs for Herman Miller - Chippenham

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Figure 5; Graph of film thickness measurements – Cobalt (RAL5003) – Herman Miller Building

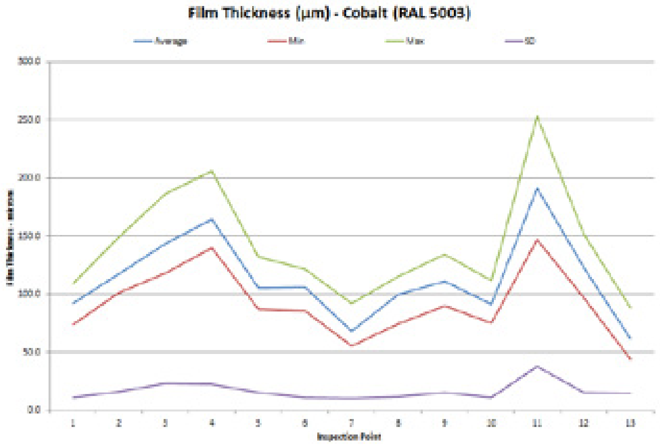

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Figure 6; Graph of colour variance L (Light & Dark) – Cobalt (RAL 5003)

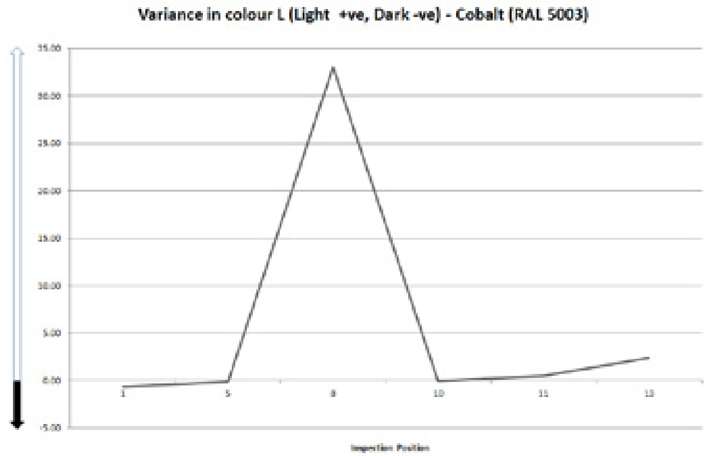

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Figure 7; Graph of colour variance A (Red & Green) – Cobalt (RAL 5003)

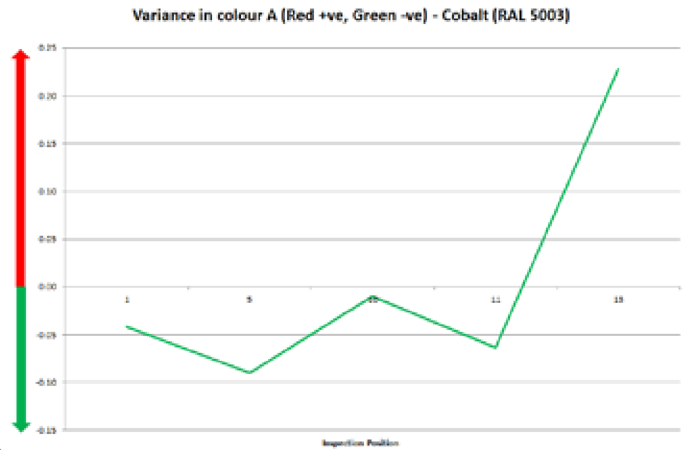

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Figure 8; Graph of variance A (Yellow & Blue) – Cobalt (RAL 5003)

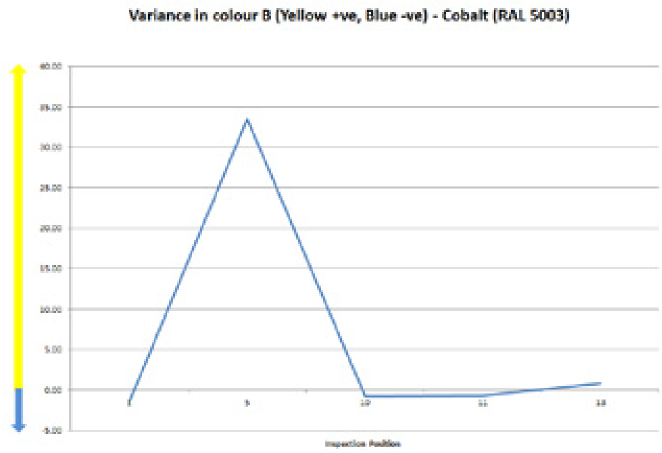

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Figure 9; Gloss variance between protected area vs exposed areas- Cobalt (RAL 5003)

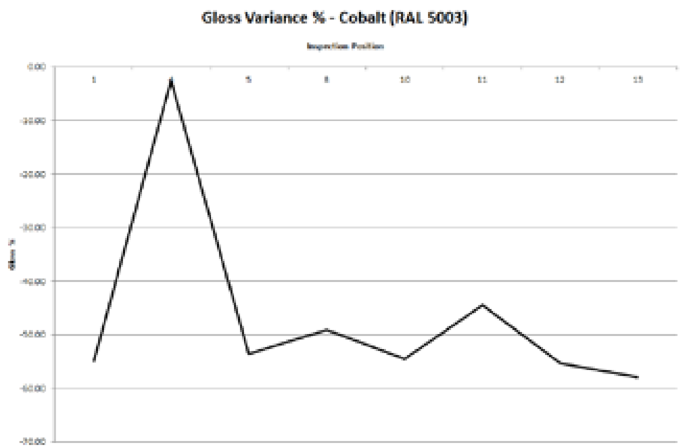

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Figure 10; Graph of film thickness measurements, Herman Miller Building – Dark Blue (RAL 5010)

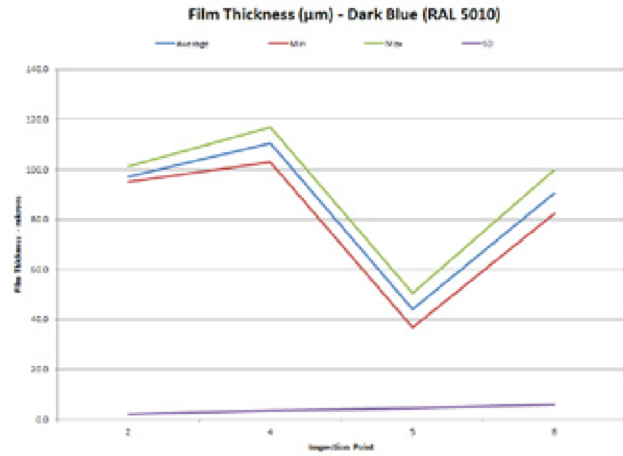

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Figure 11; Graph of colour variance L (Light & Dark) – Dark Blue (RAL 5010)

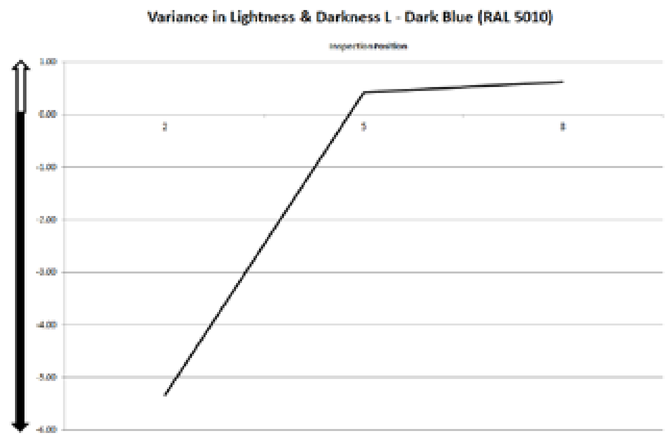

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Figure 12; Graph of colour variance A (Red & Green) – Dark Blue (RAL 5010)

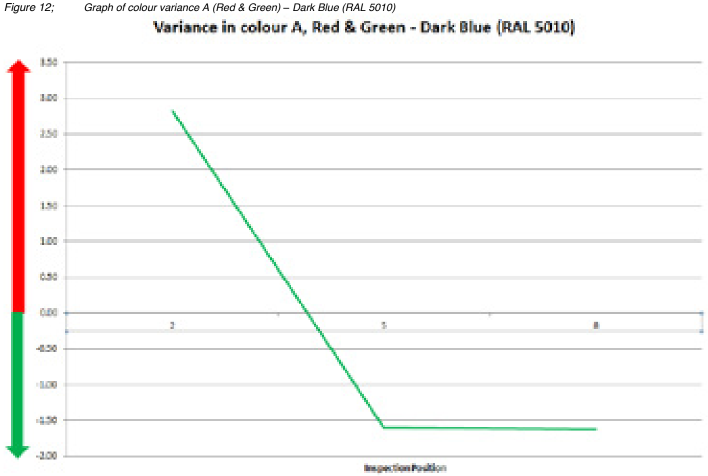

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Figure 13; Graph of colour variance B (Yellow & Blue) – Dark Blue (RAL 5010)

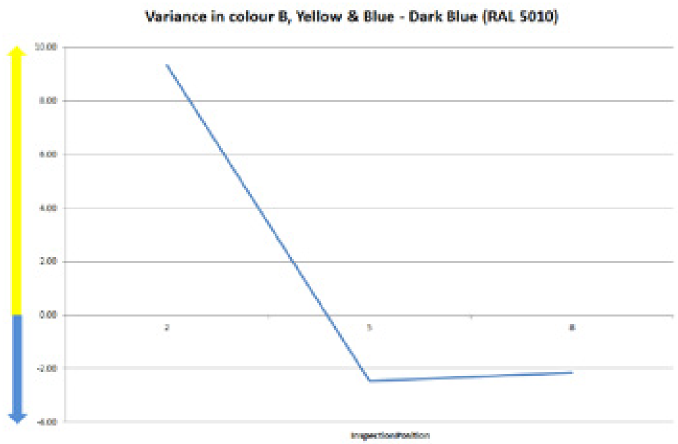

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Figure 14; Gloss variance between protected area vs exposed areas- Dark Blue (RAL 5010)

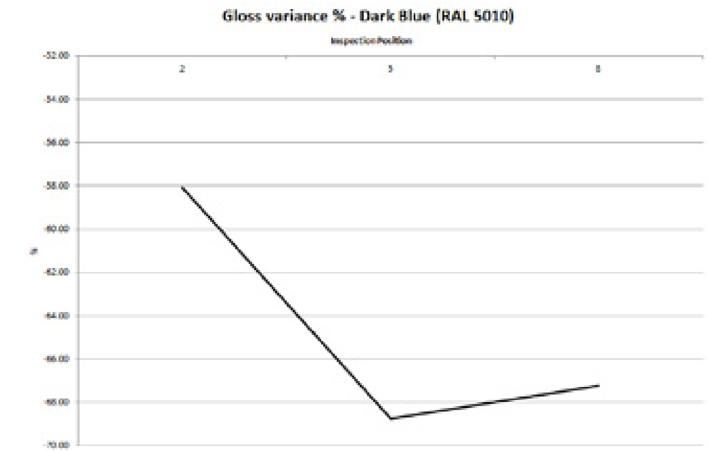

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Figure 15; Graph of film thickness measurements, Herman Miller Building – Light Blue (RAL 5012)

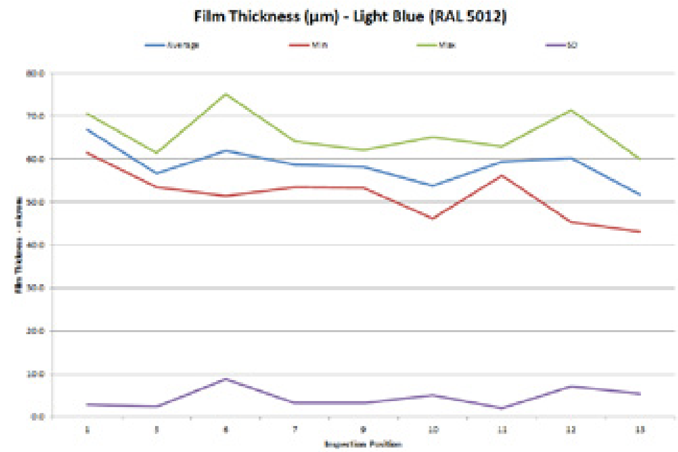

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Figure 16; Graph of colour variance L (Light & Dark) – Light Blue (RAL 5012)

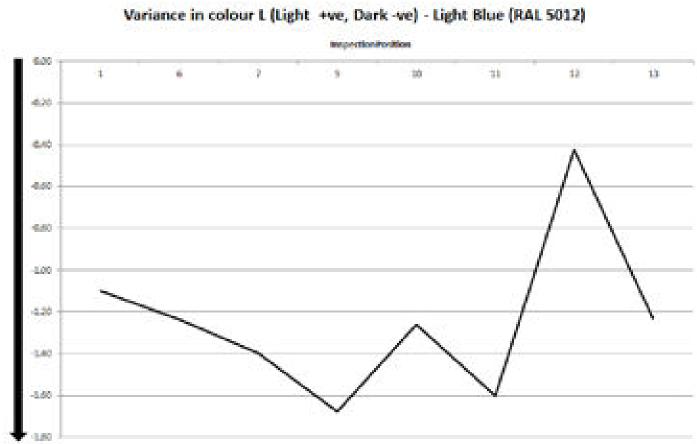

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Figure 17; Graph of colour variance A (Red & Green) – Light Blue (RAL 5012)

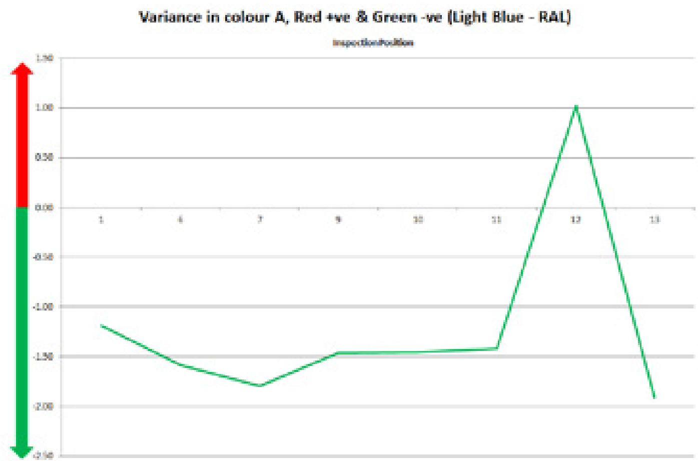

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Figure 18; Graph of colour variance B (Yellow & Blue) – Light Blue (RAL 5012)

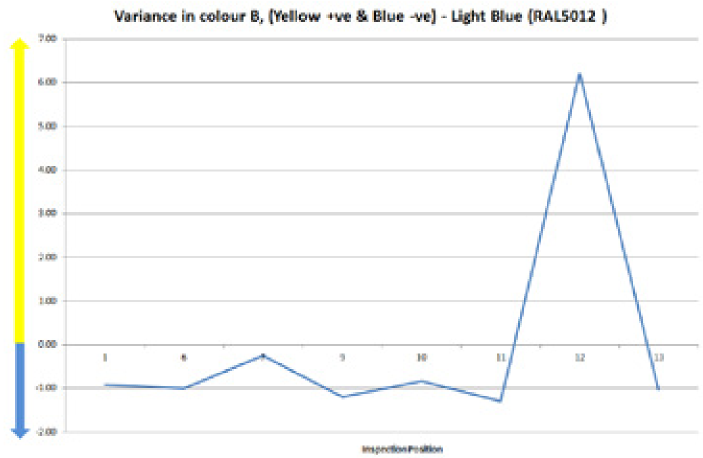

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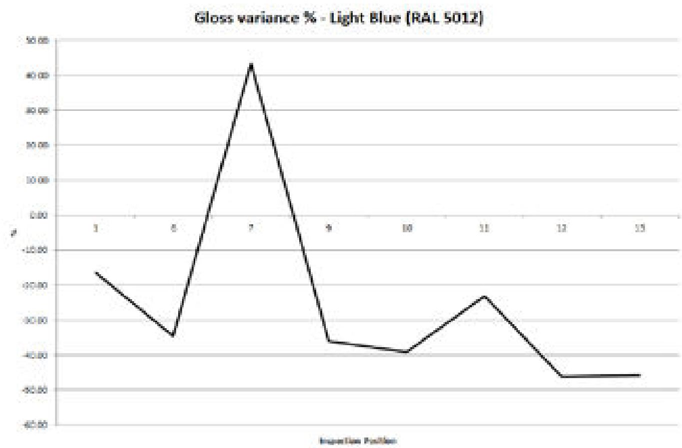
Figure 19; Gloss variance between protected area vs exposed areas- Light Blue (RAL 5012)



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Graphs for
UBS Building - London

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Figure 20; Graph of film thickness (μm) microns - UBS

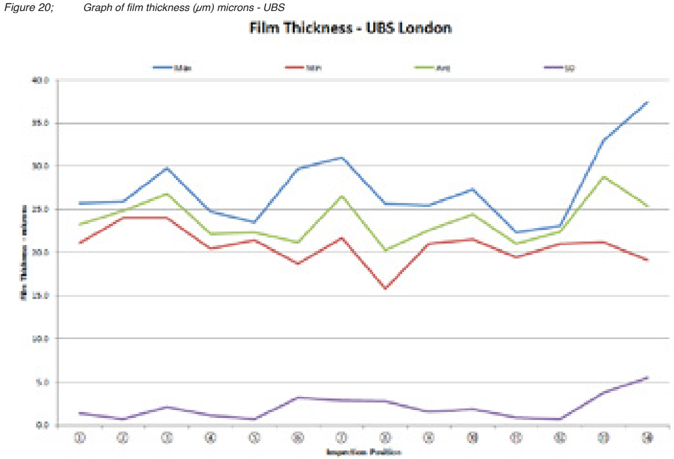

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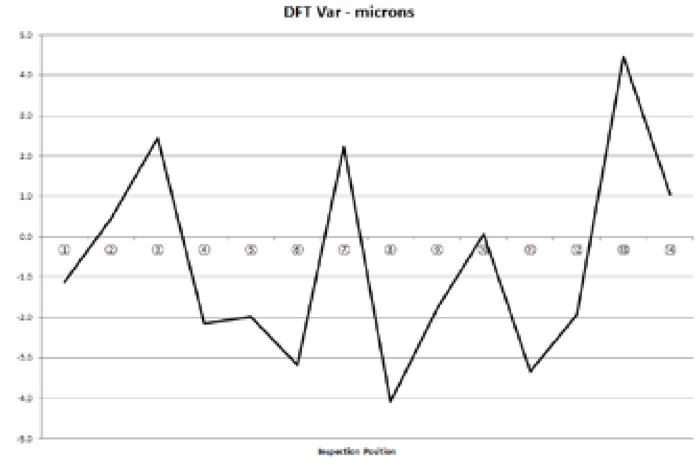
Figure 21; Graph of film thickness variance (std sample from Architects office) - microns



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Graph of colour L (Lightness & Darkness)

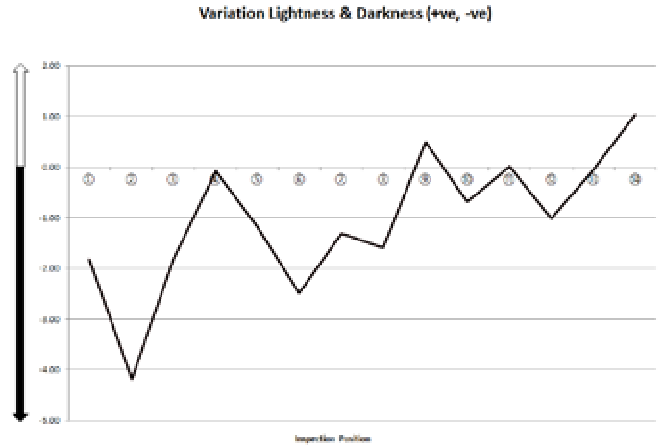

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Figure 22; Graph of colour variance A (Green & Red)

Colour Variance A (Red & Green)

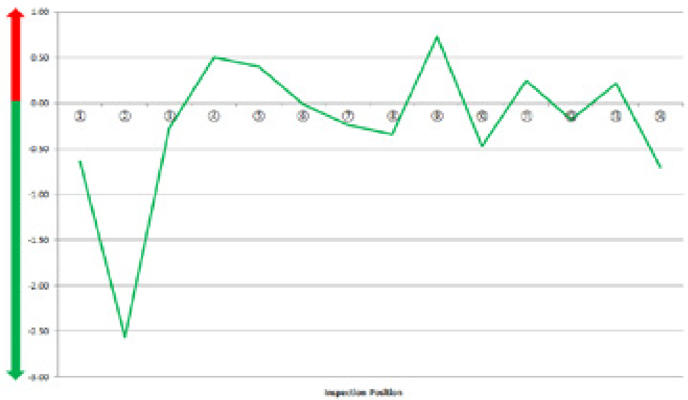

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Figure 23; Graph of colour variance B (Yellow & Blue)

Variance in colour B (Yellow & Blue)

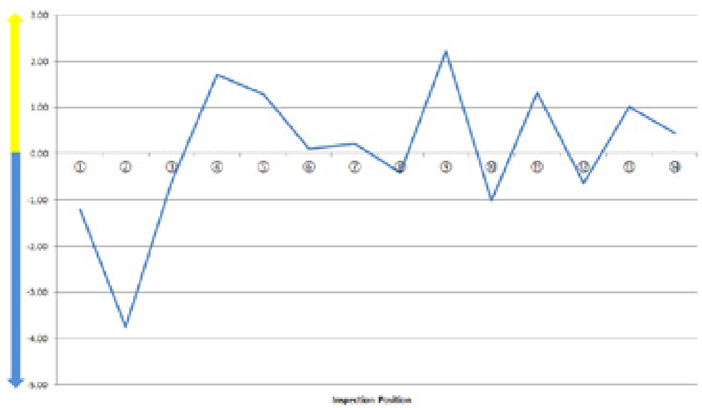

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Figure 24; Pictures from UBS – London.

UBS Building – London

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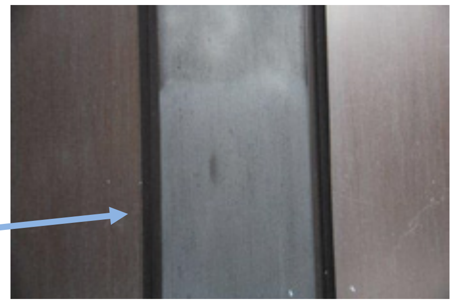

Pictures of anodised extrusion that has changed colour.

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Figure 25; Pictures from New Bodleian Library – Oxford.

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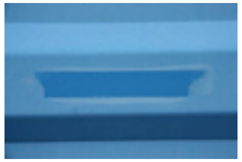
Figure 26; Pictures from Herman Miller – Chippenham.

The Picture below is showing the "Protected" area, used for the standard colour.



The pictures above show the amount of chalking, and shows a lack of maintenance on the exterior coating, once cleaned with soapy water, the colour can be seen underneath the chalking.

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Figure 27; UBS, London – Inspection Points

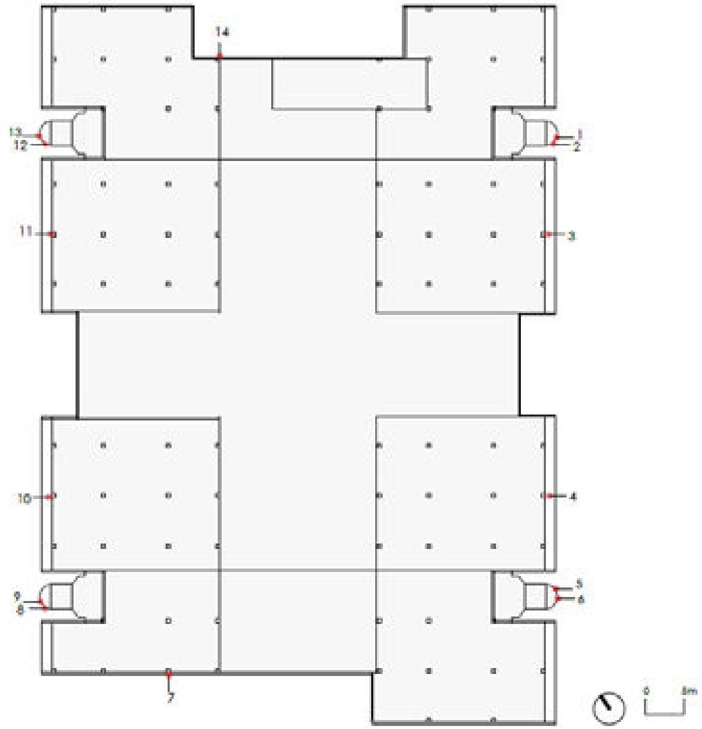

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Figure 28; New Bodleian Library, Oxford – Inspection Points

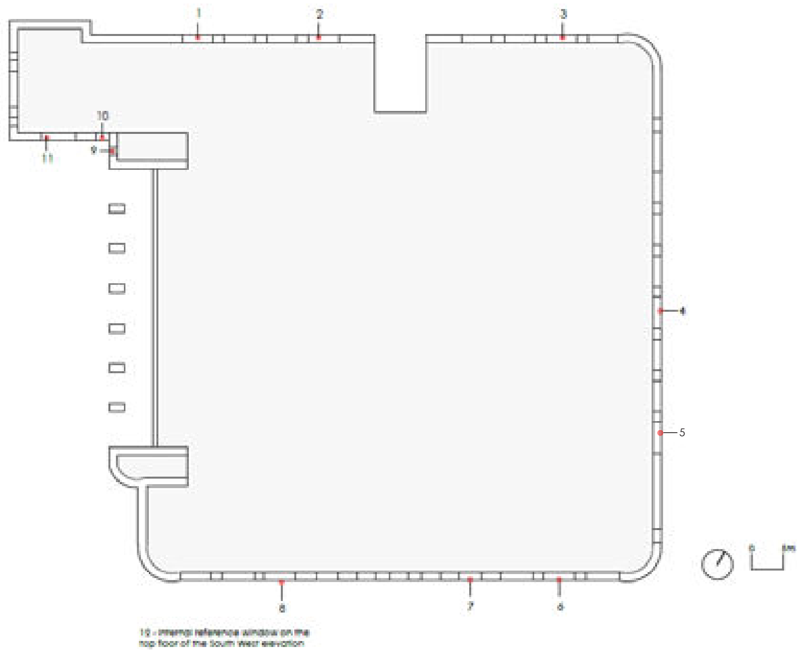

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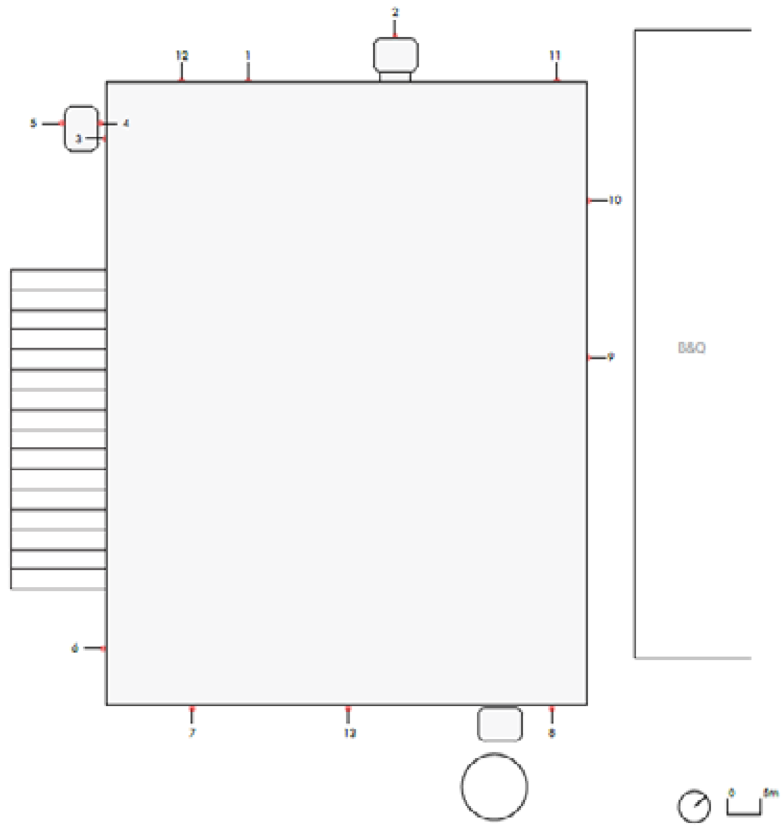
Figure 29; Herman Miller, Chippenham – Inspection Points



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APPENDIX – B

syntha pulvin testing

Qualiserve Consultancy
21 Harcourt Drive
Sutton Coldfield
West Midlands
B74 4LJ

Assessment of the Syntha Pulvin Polyester Powder Coating on the office building in Hammersmith, London

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Location:	George House 26/28 Hammersmith Grove London Formerly Wimpey Head Office
Date of Visit:	8th May, 2000

The building has been in existence for approx 26 years and is one of the longest Syntha Pulvin coated structures in the UK.

The finishing was assessed visually and instrumentally at various locations on the first and third floors, depending on access.

Visually there did not appear to be any difference between the coating on any of the floors. The condition of both the colours appeared to be good with no signs of flaking, corrosion or loss of adhesion. The adhesion was checked with the thumb nail as destructive adhesion check would spoil the cosmetic appearance of the building.

The two standards used for comparison were:

Brown RAL 8019 P2K5898 BTJF03. Gloss 88-89%
Beige RAL 1019 P2C5908 BTJE02. Gloss 82-84%

West Elevation (front) see photographs No.3 and 4

Beige RAL 1019 panels and Brown RAL 8019 extrusions. Very little dirt retention and low gloss appearance. 3rd Floor panel showed moderate chalking.

Gloss:	18-21%
After washing:	52-54%
Colour:	3 – 4 on the grey scale – whiter

Brown extrusion inner face on left-hand side of window frame (see photograph No.2)

Gloss:	9.9%
Washed:	35% moderate chalking
Colour:	3 – 4 on the grey scale

Brown extrusion inner face on right-hand side of window frame

Gloss:	46%
Washed:	68% very little chalking
Colour:	4-5 on the grey scale

Beige window frame on the inside on the 3rd floor gave a gloss reading of 78-82%. Colour 5 on the grey scale, virtually no change from original coating.

East Elevation (rear)

All panels and extrusions looked similar

1st Floor panel showed severe chalking

Gloss:	1-2%
Washed:	10%
Colour:	3-4 on the grey scale – whiter

Moderate dirt retention on the lower edges.

Brown extrusion showed severe chalking (see photograph No.1)

Gloss:	1.4%
Washed:	6 – 6.5%
Colour:	3-4 on the grey scale – lighter

3rd Floor Beige panel showed severe chalking

Gloss:	2 – 3%
Washed:	30 – 33%
Colour:	3 – 4 on the grey scale – whiter

Brown extrusion showed moderate chalking on inner face of the window frame.

Gloss:	9 –10%
Washed:	32%
Colour:	4 on the grey scale – lighter

North and South Elevations (sides)

These were not easily accessible, but the coatings appeared uniform and very similar to the rest of the building.

Summary

The cladding on this building is in a remarkably good state for its age. Any colour and gloss change has changed uniformally so preserving the aesthetic appearance of the building. As expected, those areas having the most sunlight have shown the largest change in gloss and the highest degree of chalking. The coating, although showing signs of wear, is still protecting the substrate from corrosion.

B.E. Myatt
Qualiserve Consultancy
12th May, 2000

BEM/vms/20418

Assessment of the Syntha Pulvin Polyester Powder Coating on the office building in Hammersmith, London

Location: George House
26/28 Hammersmith Grove
London
Formerly Wimpey Head Office
Date of Visit: 7th February 2006

The building has been in existence for 33 years (since 1973) and is one of the longest Syntha Pulvin coated structures in the UK.

The coating was assessed visually and instrumentally at each aspect of the building.

Visually the powder coated sections had a uniform colour and gloss on each side of the building. The condition of both the curtain walling appeared to be good with no signs of flaking, corrosion or loss of adhesion. The adhesion was checked with the thumb nail as destructive adhesion check would spoil the cosmetic appearance of the building.

The two standards used for comparison were:

Brown RAL 8019 P2K5898 Gloss 80%
Beige RAL 1019 P2C5908 Gloss 80%

West Elevation (front) see photographs No.1 and 2 (no access to cladding panels on this side)

Beige RAL 1019 panels and Brown RAL 8019 extrusions. Very little dirt retention and low gloss appearance.

Beige window frame on the inside on the 3rd floor gave a gloss reading of 78-82%. Colour 5 on the grey scale, virtually no change from original coating.

No sign of corrosion was evident, even on the bare, cut edges at the base of the mullions.

East Elevation (rear)

All panels and extrusions looked similar

1st Floor panel showed chalking
Beige panel

Gloss:	1%
Washed:	9-12%
Colour:	4 on the grey scale – paler

Moderate dirt retention on the lower edges.
Brown extrusion showed severe chalking (see photograph No.)

Gloss:	1%
Washed:	2 – 3%
Colour:	1 on the grey scale – lighter

No sign of corrosion was evident, even on the bare, cut edges at the base of the mullions.

North and South Elevations (sides)

These were not easily accessible, but the coatings appeared uniform and very similar to the rest of the building.

On the connecting bridge between the two blocks there was a shaded area that did not get much direct sunlight on the lowers section. A much higher gloss retention was recorded in this area,

Beige panel

Gloss:	55%
Washed:	67%
Colour:	4 on the grey scale – lighter

Brown mullion

Gloss:	18%
Washed:	28%
Colour:	3 on the grey scale – lighter

No sign of corrosion was evident, even on the bare, cut edges at the base of the mullions.

Summary

The cladding on this building is in a remarkably good state for its age. Any colour and gloss change has changed uniformally so preserving the aesthetic appearance of the building. As expected, those areas having the most sunlight have shown the largest change in gloss and the highest degree of chalking. The coating, although showing signs of wear, is still protecting the substrate from corrosion.

bibliography

Bibliography

Abel, C. (1989), *From hard to soft machines*, in Lambot, I. (ed.), *Norman Foster: Building and Projects of Foster Associates, Volume 3: 1978–1985*, Hong Kong, Watermark, pp. 10–19

Anon (1953), *Aluminum Skyscraper*, Popular Mechanics, December Vol. 100, No. 6, pp. 86–87

Alcoa (1953), *Aluminum on the Skyline, Pittsburgh*

Alexander, W. and Street, A. (1977), *Metals in the Service of Man*, 6th edition, Penguin, London

Architectural Powder Coatings (2008), *Maintenance of Powder Coated Aluminium Articles*, available online at http://architecturalpowdercoatings.co.uk/docsblog/docsblog/index_files/New%20Maintenance%20Sheet.pdf (accessed July 2013)

Ashby, J. (1999) *The Aluminium Legacy: the history of the metal and its role in architecture*, Construction History Vol. 15, pp. 79–90

Bagsværd Church, *They Built the Church*, available online at www.bagsvaerdkirke.dk/index.php?id=108 (accessed September 2015)

Baldry, A. L. (1905), *A notable decorative achievement by W. Reynolds-Stephens*, The Studio, 34(143), pp. 3–15

Barsottini, D. (ed.) (2006), *La Chiesa di San Gioacchino ai Prati di Castello in Roma*, Formello, Miligraf, Rome

Barton, K. (1976), *Protection against Atmospheric Corrosion: Theories and Methods*, Wiley, London

BBC News (2013), *WWII Dornier Do-17 bomber raised from the Channel*, 10 June, available online at www.bbc.co.uk/news/uk-22850596 (accessed September 2015)

Brand, S. (1994), *How Buildings Learn: What Happens After They're Built*, Viking Press, New York

Brookes, A. (1983), *Cladding of Buildings*, Construction Press, Harlow

Brookes, A. (1985), *Concepts of Cladding*, Construction Press, Harlow

Brookes, A. (1985), *Development and use of gaskets in cladding systems*, Roofing, Cladding & Insulation, February, pp. 29–33

Brookes, A. and Grech, C. (1990), *Building Envelope*, Butterworth, Oxford

Brookes, A. and Grech, C. (1992), *Connections*, Butterworth, Oxford

Brookes, A. and Stacey, M. (1985), *Aluminium Extrusions*, Architects' Journal, 20 November, pp. 152–157

Brookes, A. and Stacey, M. (1987), *Fast Facades*, Building Products, December, pp. 88–91

Brookes, A. and Stacey, M. (1988), *Overcladding: an uncertain panacea,* Architects' Journal, 27 January, pp. 67–71

Brookes, A. and Stacey, M. (1988), *Cladding Product Review*, AJ Focus, October, pp. 31–55

Brookes, A. and Stacey, M. (1990), *Cladding Product Review*, AJ Focus, March, pp. 25–42

Buckley, Canon D. (1987), *The Parish of Fenny Bentley and Its Church of St Edmund, King and Martyr*, Ashbourne

Callicot, N. (2001), *Computer-Aided Manufacture in Architecture*, Architectural Press, Oxford

Carlisle S., Frielander E., and Faircloth B., (2015), *Aluminium and Life Cycle Thinking,* Cwningen Press, Llundain

Catini, R. (1997), *La Vicenda di San Gioacchino ai Prati*, Roma Moderna E Contemporanea, 5(1), pp. 209–235

Clarke, S. (1994), *The restoration of Eros*, Context, 42, pp. 23–24, available online at http://ihbc.org.uk/context_archive/42/clarke.htm (accessed August 2013)

Coley, C. (2006), *CIMT*, in von Vegesack, A., Dumont D'Ayot, C. and Reichlin, B. (eds), *Jean Prouvé: The Poetics of the Technical Object*, Vitra Design Museum, Stiftung GmbH, Weil am Rhein, pp. 160–165.

Coltman, R. (2010), *Daily Express Building, London*, *Modernist Britain*, 28 September, available online at www.modernistbritain.co.uk/post/building/Daily+Express+Building (accessed November 2013)

Cordner, R. J. (1990), *Atmospheric corrosion survey of New Zealand*, British Corrosion Journal, 25(2), pp. 115–118

Crittall Windows, *Maintenance of Steel Windows*, available online at www.crittall-windows.co.uk/products/maintenance-of-steel-windows (accessed September 2015)

CurveX Temperature Profiling Systems, *Powder Coating*, available online at www.curvex.nl/applications/powder-coating (accessed September 2013)

Danz, E. (1962), *Architecture of Skidmore, Owings & Merrill, 1950–1962*, Monacelli Press, New York

Davies, C. (1989), *Hongkong Bank cladding*, in Lambot, I. (ed.), *Norman Foster: Building and Projects of Foster Associates, Volume 3: 1978–1985*, Hong Kong, Watermark, pp. 220–231

Davies, C. (2005), *The Prefabricated Home*, Reaktion Books, London

Deplazes, A. (ed.) (2008), *Constructing Architecture: Materials, Processes, Structures – A Handbook*, Birkhäuser, Basel

Drexler, A. (2009), *Architecture of Skidmore, Owings & Merrill, 1963–1973*, Monacelli Press, New York

Duffy, F. (1990), *Measuring building performance*, Facilities, 8(5), pp. 17–21

Dulux Trade (2008), *Weathershield Exterior Preservative Primer+*, available online at http://dulux.trade-decorating.co.uk/web/pdf/datasheets/203.pdf (accessed July 2013)

Dulux Trade, *Weathershield*, available online at www.duluxtradepaintexpert.co.uk/brands/dulux-trade/weathershield (accessed September 2015).

Ford, E. R. (1996), The *Details of Modern Architecture, Volume 2: 1928 to 1988*, The MIT Press, Cambridge, MA

Futagawa, Y. ed., Bauchet, B. and Vellay, M. (1988), *The Maison de Verre: Pierre Chareau*, ADA Edita, Tokyo

Giedion, S. (1941), *Space, Time and Architecture: The Growth of a New Tradition*, Harvard University Press, Cambridge, MA

Grimshaw, N. (ed.) (1988), *Nicholas Grimshaw & Partners: Book 1 Product*, NGP, London

Grinberg I. and Plateau J. (2013) *Aluminium Passion: The Treasure-Trove of the Collection of Jean Plateau – IHA*, Les Éditions Du Mécène, Paris

Hallet, J., Hathaway, W. and Stanforth, B. (2013), *Between Furniture and Architecture*, Cwningen Press, Llundain

Harris, D., *The World's Oldest Aluminium Casting*, available online at www.dcsoc.org.uk/filemanager_net/files/The_Worlds_Oldest_Aluminium_Castings.pdf (accessed August 2013)

Hix, J. (1974), *The Glass House*, The MIT Press, Cambridge, MA

Hrausky, A. and Kozelj, J. (2007), *An Architectural Guide to Ljubljana: 107 Selected Buildings*, Rokus Gifts, *Ljubljana*

Interpon, *Sustainability*, available online at www.interpon.com/about-us/sustainability (accessed September 2013)

Jackson, N. (1996), *The Modern Steel House,* Dah Hua Press, Hong Kong

Kalzip Ltd (2011), *Durability and Corrosion Testing*, available online at www.kalzip.co.uk/PDF/uk/BAM%20Durability%20and%20corrosion%20testing.pdf (accessed September 2013)

Lipman, L. (1986), *Frank Lloyd Wright and the Johnson Wax Buildings*, Rizzoli, New York

MacQueady, J. (1940), *Gilbert Scott's New Bodleian Library,* Architectural Review, October, (Editor J.M. Richards, under the pseudonym James MacQueady).

Marcelli, E., *San Gioacchino in Prati*, Arti Grafiche, La Moderna, Rome

Menges, A. (1974), *Architecture of Skidmore, Owings & Merrill, 1963–1973*, Monacelli Press, New York

Morcillo M., Almeida E., et al., (2003) *Behaviour of Painted Aluminium in Ibero-American Atmospheres*, Rev. Metalurgia, Vol. Extra, pp.151-156

Museum Wales, *Historical Buildings at St Fagans: Prefab*, available online at www.museumwales.ac.uk/stfagans/buildings/prefab (accessed April 2013)

Myatt B.E. (2000), *Qualiserve Consultancy Report*: *Visit 8.5.2000*, courtesy Syntha Pulvin

Newhouse, V. (1989), *Wallace K. Harrison, Architect*, Rizzoli, New York

Nichols S. (ed.) (2000), *Aluminum by Design*, Abarams, New York

Olsen Doors & Windows Ltd, *Care & Maintenance*, available online at www.olsenuk.com/information/care-maintenance (accessed September 2015)

Parks, L. (1986), *Aluminium in the Home and Office*, in Barry, A. (ed.), *Aluminium 1886–1986*, Morgan-Grampian for ALFED, London, p. 42.

Pawley, M. (1983), *New age detailing at Renault by Foster*, Architects' Journal, 15 June, pp. 40–45.

Pawley, M. (1993), *A dose of morphine: the rise and fall of public sector housing*, Frieze, 10, available online at www.frieze.com/issue/article/a_dose_of_morphine (accessed December 2013)

Peters, N. (2013), *Jean Prouvé: 1901–84: The Dynamics of Creation*, Taschen, Cologne

Pevsner, N., Fleming, J. and Honour, H. (1971), *Lexikon der Weltarchitektur*, Prestel, London

Pierdominici, M. C. (1997), *Chiesa di San Gioacchino ai Prati di Castello: Note di Restauro*, Bollettino D'Arte, 82(100), pp. 159–170

Prouvé, J. (1971), *Jean Prouvé: Une architecture par l'industrie,* Huber, B. and Steinegger, J.-C. (eds), Artemis, Zurich

Qualicoat (2011), *Recommendations for Care of Coated Aluminium*, available online at www.qualicoat.net/main/downloads.html (accessed August 2013)

Qualicoat (2013), *No. 1: Guide for Cleaning and Maintenance of Powder Coated Aluminium*, available online at www. qualicoatuki.org/downloads_files/01_cleaning_1301.pdf (accessed July 2013)

Qualiserve (2006), *Qualiserve Consultancy Report: Visit 7.2.2006*, courtesy Syntha Pulvin

Nichols S. C., ed., (2000), Aluminum by Design, Abarams, New York

Ratcliffe, J. (ed.) (2008), *Aluminium and Sustainability: Cradle to Cradle*, Council for Aluminium in Building, Stonehouse

Reid, C. (1976), *Courant in Göttingen and New York : The Story of an Improbable Mathematician*, Springer, New York

Román A. (2002), *Eero Saarinen: An Architecture of Multiplicity*, Laurence King, London

Rostron, R. M. (1964), *Light Cladding of Buildings*, Architectural Press, Oxford

Russell B. (19810, *Building Systems, Industrialization and Architecture*, Wiley, London

Sadolin (2012), *Woodshield*, available online at www.sadolin.co.uk/wp-content/uploads/data-sheets/sadolin-woodshield-technical-data-sheet.pdf (accessed July 2013)

Salant, K. (2000), *A 1963 home framed and clad in aluminum is still virtually maintenance-free today*, Los Angeles Times, 2 April

Serraino, P. (2006), *Saarinen*, Taschen, Cologne

Sherwood, J. and Pevsner, N. (1974), *The Buildings of England:* Oxfordshire, Yale University Press, New Haven

Skerrey, E. W. (1982), *Long-Term Atmospheric Performance of Aluminum and Aluminum Alloys,* Wiley, New York

Smart Systems (2005), *Cleaning, Maintenance and Repair: Aluminium Windows, Doors* *and Architectural Products*, available online at www.smartsystems.co.uk/asset/?id=133 (accessed September 2015)

Sowinski, G. and Sprowls, D. O. (1982), *Weathering of Aluminum Alloys*, Wiley, New York

Stacey, M. (1988), *Maximum Vision*, AJ Focus, October, pp. 14-15

Stacey, M. (2001), *Component Design*, Architectural Press, Oxford

Stacey, M. *Hongkong and Shanghai Bank, HQ*, The Future Builds with Aluminium, available online at http://greenbuilding.world-aluminium.org/nc/benefits/durable/hongkong-and-shanghai-bank-hq.html?sword_list[]=bank (accessed September 2013)

Stacey, M. (2010), *Aluminium, Architecture and Human Ecology*, in Katgerman, L. and Soetens, F. (eds), *New Frontiers in Light Metals: Proceedings of the 11th International Aluminium Conference*, IOS Press, Amsterdam, pp. 3–12

Stacey, M. (2011), *Concrete: a studio design guide*, RIBA Publishing, London

Stacey, M. (2015), *Aluminium: Flexible and Light*, Cwningen Press, Llundain

Stacey, M. (2015), *Aluminium: Recyclability and Recycling*, Cwningen Press, Llundain

Steel Window Association, *Aftercare and Maintenance of Steel Windows*, available online at www.steel-window-association.co.uk/assets/files/fs4.pdf (accessed September 2015)

Tabor, J. (1996), *Otto Wagner: Die Österreichische Postsparkasse*, Falter Verlag, Vienna

Turner, M. J., Clough, R. W., Martin, H. C. and Topp, L. J. (1956), *Stiffness and deflection analysis of complex structures*, Journal of Aeronautical Sciences, 23(9), pp. 805–823

United Anodisers, *Lifetime Guarantee*, available online at www.unitedanodisers.com/index.php/the-ua-group/lifetime-guarantee.html (accessed September 2015)

Utzon, J., Godtfred, J., Mortensen, B., Schwartz, M., Simonsen, S., Weston, R., Ulzon, J. and Ulzon, L. (2005), *Bagsværd Church: v.2: Jørn Utzon Logbook*, Edition Bløndal, Hellerup

Vale, B. (1995), *Prefabs: A History of the UK Temporary Housing Programme*, E & FN Spon, London

Vantage Windows and Doors, *Warranty & Service*, available online at www.vantagedoorsandwindows.co.uk/warranty-service.html (accessed July 2013)

Vargel C. (2004), *The Resistance of Aluminium to Atmospheric Corrosion, Elsevier, Oxford,*

Venacque, A.(2006), *A Prototypical Legacy* in von Vegesack, A., Dumont D'Ayot, C. and Reichlin, B. (eds), *Jean Prouvé: The Poetics of the Technical Object*, Vitra Design Museum, Stiftung GmbH, Weil am Rhein, pp. 356–361.

Wagner O. (1896), *Moderne Architektur*, Verlag von Anton Schroll & Co., Vienna.

Wilkinson, C. (1991), *Supersheds: The Architecture of Long-Span Large-Volume Buildings*, Butterworth, Oxford

Wilkinson Eyre Architects (2010), *New Bodleian Library: Architect's Statement*, 26 February, available online at www.bodleian.ox.ac.uk/__data/assets/pdf_file/0004/65884/Wilkinson-Eyre-Architects-Architects-statement.pdf (accessed September 2015)

de Wit, W. and Alexander, C. J. (2013), *Overdrive: LA Constructs the Future, 1940–1990*, Getty Research Institute, Los Angeles

Wood for Good (2013), *Why Use Wood?*, available online at www.woodforgood.com/why-choose-wood (accessed July 2013)

Wrightson, D. (2001), *Sash Windows: Painting and Draught-Proofing*, available online at www.buildingconservation.com/articles/sashwindows/sash_windows.htm (accessed July 2013)

Yeomans, D. (1998), *The pre-history of the curtain wall*, Construction History, Vol. 14, p. 59–82

Standards

AAMA 501.1-05 (2005) Standard Test Method Exterior Windows, Curtain Walls and Doors for Water Penetration Using Dynamic Pressure, American Architectural Manufacturers Association, Schaumburg, IL

AAMA 2603-02 (2002) Voluntary Specification, Performance Requirements and Test Procedures for Pigmented Organic Coatings on Aluminum Extrusions and Panels, American Architectural Manufacturers Association, Schaumburg, IL

AAMA 2604-05 (2005) Voluntary Specification, Performance Requirements and Test Procedures for High Performance Organic Coatings on Aluminum Extrusions and Panels, American Architectural Manufacturers Association, Schaumburg, IL

AAMA 2605-05 (2005) Voluntary Specification, Performance Requirements and Test Procedures for Superior Performing Organic Coatings on Aluminum Extrusions and Panels, American Architectural Manufacturers Association, Schaumburg, IL

BS 1470:1987 Specification for wrought aluminium and aluminium alloys for general engineering purposes: plate, sheet and strip (withdrawn), BSI, Hemel Hempstead

BS 1471:1972 Specification for wrought aluminium and aluminium alloys for general engineering purposes - drawn tube (withdrawn), BSI, Hemel Hempstead

BS 1474:1987 Specification for wrought aluminium and aluminium alloys for general engineering purposes: bars, extruded round tubes and sections (withdrawn), BSI, Hemel Hempstead

BS 3987:1991. Specification for anodic oxidation coatings on wrought aluminium for external architectural applications, BSI, Hemel Hempstead

BS 5368-1:1976 Methods of testing windows. Air permeability test (withdrawn), BSI, Hemel Hempstead

BS 5368-2:1980 Methods of testing windows. Watertightness test under static pressure (withdrawn), BSI, Hemel Hempstead

BS 5368-3:1978 Methods of testing windows. Wind resistance tests (withdrawn), BSI, Hemel Hempstead

BS 6001-1:1999+A1:2011, ISO 2859-1:1999 Sampling procedures for inspection by attributes. Sampling schemes indexed by acceptance quality limit (AQL) for lot-by-lot inspection, BSI, Hemel Hempstead

BS 7543:2015 Guide to durability of buildings and building elements, products and components, BSI, Hemel Hempstead

BS EN 1026:2000 Windows and doors. Air permeability. Test method, BSI, Hemel Hempstead

BS EN 1027:2000 Windows and doors. Watertightness. Test method, BSI, Hemel Hempstead

BS EN 12211:2000 Windows and doors. Resistance to wind load. Test method, BSI, Hemel Hempstead

BS EN12206-1:2004 Paints and varnishes. Coating of aluminium and aluminium alloys for architectural purposes. Coatings prepared from coating powder, BSI, Hemel Hempstead

BS EN ISO 2360:2003 Non-conductive coatings on non-magnetic electrically conductive basis materials. Measurement of coating thickness. Amplitude-sensitive eddy current method, BSI, Hemel Hempstead

BS EN ISO 2813:2014 Paints and varnishes. Determination of gloss value at 20 degrees, 60 degrees and 85 degrees, BSI, Hemel Hempstead

BS EN ISO 7599:2010 Anodizing of aluminium and its alloys. General specifications for anodic oxidation coatings on aluminium, BSI, Hemel Hempstead

[BS] PD 6484:1979 *Commentary on Corrosion at Bimetallic Contacts and its Alleviation*, BSI, Hemel Hempstead

ISO 2859-1:1 1999 Sampling procedures for inspection by attributes -- Part 1: Sampling schemes indexed by acceptance quality limit (AQL) for lot-by-lot inspection, ISO, Geneva

ISO 4628-11: 2011 Paints and varnishes. Evaluation of degradation of coatings, ISO, Geneva

ISO 7724-3: 1984 Paints and Varnishes. Colorimetry, Part 3: Calculation of colour differences, (withdrawn), ISO, Geneva

ISO 12944: 1998 Paints and Varnishes. Corrosion protection of steel structures by protective paint systems (Parts 1–8), ISO, Geneva

Websites

Aluminium Finishing Association, www.afauk.org.uk

The Aluminium Story, www.thealuminiumstory.com

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The Towards Sustainable Cities Research Team

Michael Stacey Architects

The practice has a thoughtful approach to the design of architecture. Michael Stacey Architects' aim is to contribute to people's lives and the culture of contemporary society through an informed knowledge of humanity, study of architectural precedents and urban habitats, combined with a detailed understanding of materials and fabrication processes. This knowledge base is underscored by a long-term commitment to research. The benefit of using a component-based architecture and off-site manufacturing is that it is possible to create high-quality and cost-effective architecture delivered with the shortest possible site time. This has been demonstrated on projects at a number of scales including the Boat Pavilion, Regional Rail Stations, Cardiff Bridges and Ballingdon Bridge. The design approach of Michael Stacey Architects is based on systems of components, yet each architectural project is client and site specific.

www.s4aa.co.uk

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The practice brings together the experience and talents of nearly 100 professionals of diverse backgrounds and abilities in a practice that is recognised worldwide. KieranTimberlake's projects include the programming, planning and design of new structures as well as the conservation, renovation and transformation of existing buildings, with special expertise in education, government, arts and culture, civic and residential projects. KieranTimberlake seeks ways to improve the art, quality and craft of architecture through research into new materials, processes, assemblies and products.

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Architecture and Tectonics Group at The University of Nottingham

The Architecture and Tectonics Research Group [ATRG] addresses the core of architecture including design as research and research that supports and stimulates the design of high-quality contemporary architecture and infrastructure. Themes within this research group include: architecture as a discipline, craft, digital fabrication, form finding, off-site manufacture, façade systems, tectonics, durability, emergent materials, zero-carbon architecture and human ecology.

www.nottingham.ac.uk/research/groups/atrg/index.aspx

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Aluminium Recyclability and Recycling

Aluminium is almost infinitely recyclable and this is well understood. This research identifies that aluminium-based projects dating back to 1950 that have been disassembled have all been recycled. 1950 is the first year of entries in IAI's global mass flow model. The research reviews the reasons why buildings are demolished and rates of material recovery at the end of use. Key examples of short-life and relocatable architecture are set out, alongside the future role of Design for Disassembly [DfD]. This research also identifies that there is a much wider uptake of cast aluminium components in architecture than may have been expected.

Written by Michael Stacey.

Aluminium and Life Cycle Thinking

Life cycle thinking challenges architects, engineers and contractors to be mindful of the life history of any manufactured product and more specifically to understand the inputs (energy and water) and outputs (emissions to the environment) that result from the transformation of matter into product and from product to disposal. This report uses Life Cycle Assessment, a modelling method, to quantify and compare the environmental impacts and benefits associated with aluminium building components to those associated with alternative materials.

Written by Stephanie Carlisle, Efrie Friedlander, and Billie Faircloth.

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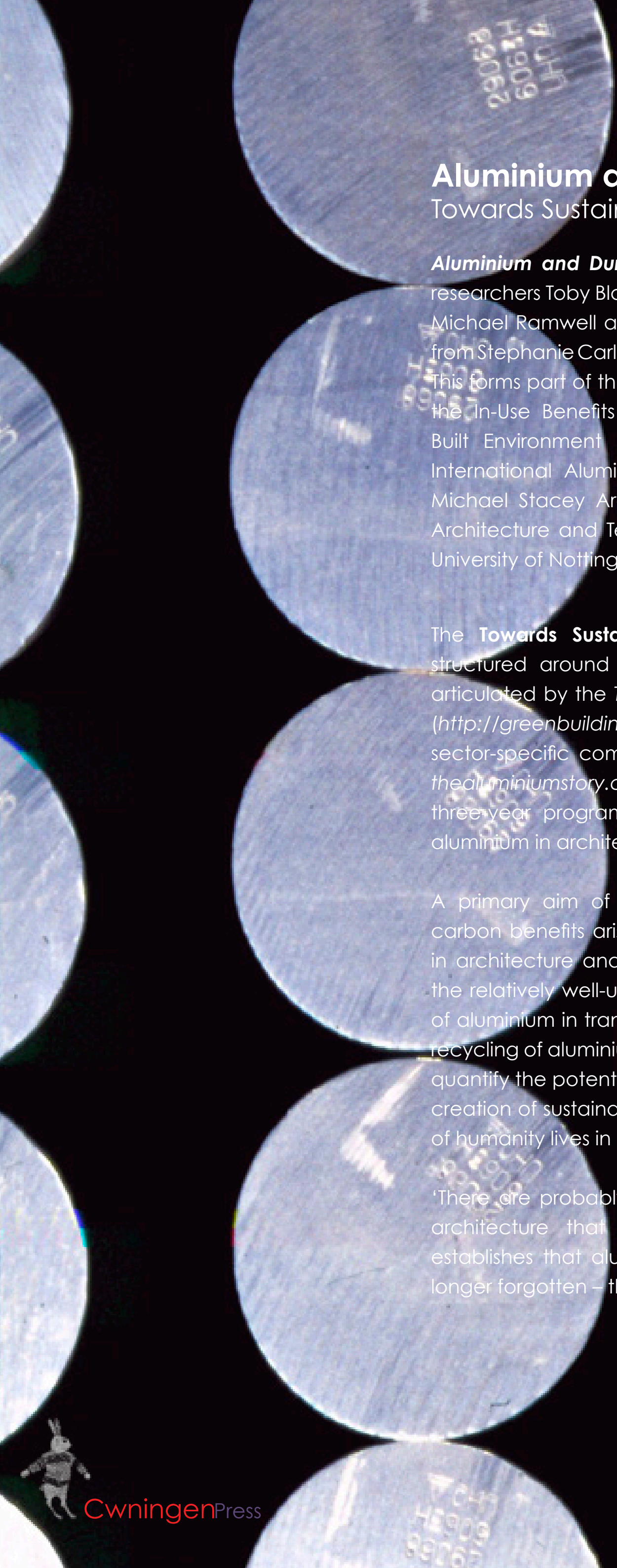
Heelis, The National Trust Headquarters,
Swindon, architect Feilden Clegg Bradley, 2005



Aluminium and Durability

Towards Sustainable Cities

Aluminium and Durability, written by Michael Stacey, with researchers Toby Blackman, Laura Gaskell, Jenny Grewcock, Michael Ramwell and Benjamin Stanforth, with further input from Stephanie Carlisle and Billie Faircloth of KieranTimberlake. This forms part of the Towards Sustainable Cities: Quantifying the In-Use Benefits of Aluminium in Architecture and the Built Environment Research Programme, funded by the International Aluminium Institute [IAI] and undertaken by Michael Stacey Architects with KieranTimberlake and the Architecture and Tectonics Research Group [ATRG] at The University of Nottingham.

The **Towards Sustainable Cities Research Programme** is structured around the primary benefits of aluminium, as articulated by the *The Future Builds with Aluminium* website (*http://greenbuilding.world-aluminium.org*), which is a sector-specific component of *The Aluminium Story* (*http://thealuminiumstory.com*). Towards Sustainable Cities is a three-year programme quantifying the in-use benefits of aluminium in architecture and the built environment.

A primary aim of this research is to quantify the in-use carbon benefits arising from the specification of aluminium in architecture and the built environment, to complement the relatively well-understood emission savings from the use of aluminium in transportation applications and through the recycling of aluminium scrap. A vital goal of this research is to quantify the potential contribution of aluminium towards the creation of sustainable cities – a key task now that over half of humanity lives in urban areas.

'There are probably 100s of examples of aluminium-based architecture that are fit but forgotten.' This research establishes that aluminium-based architecture is fit but no longer forgotten – this excellence should be celebrated.

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