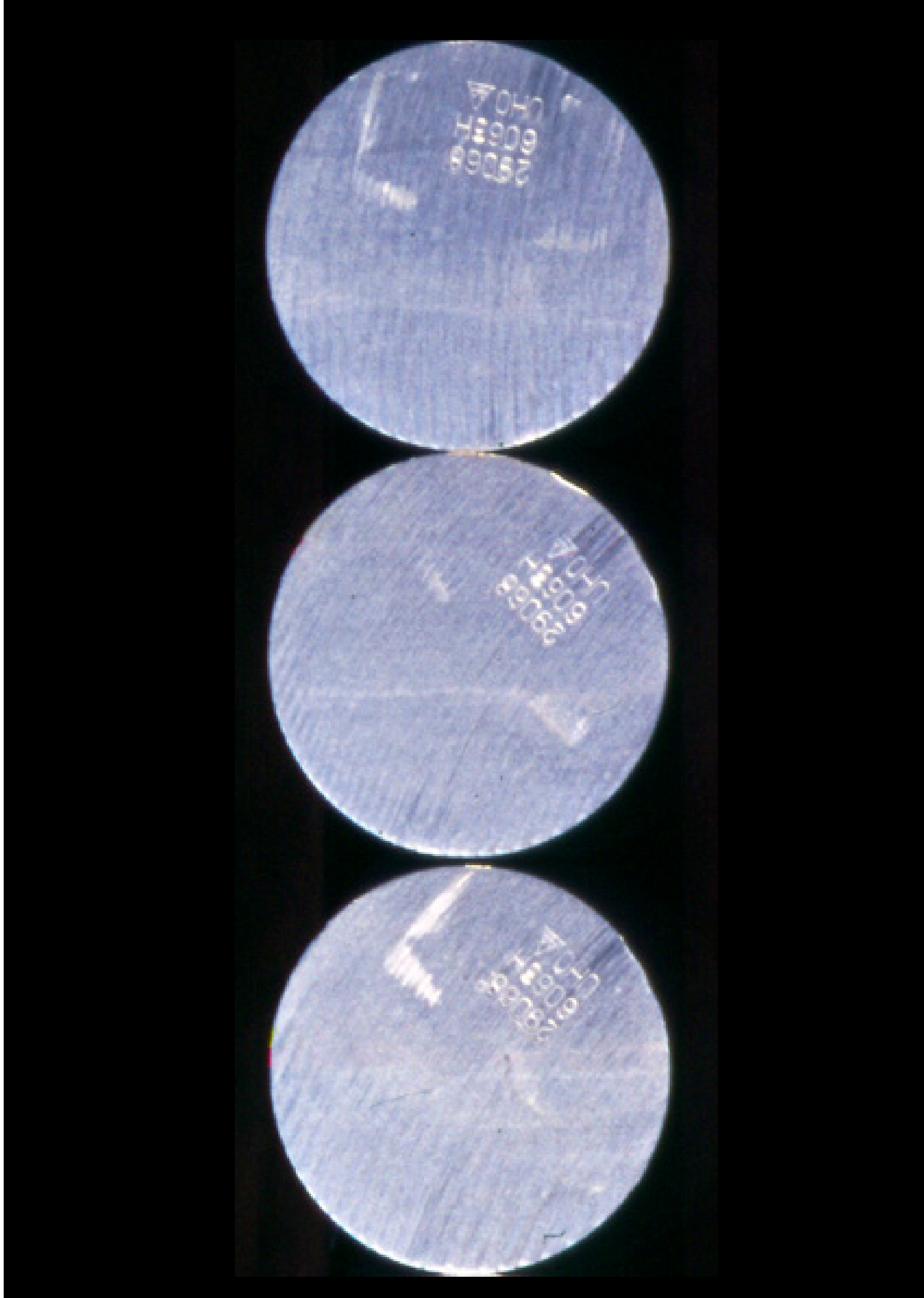
Aluminium Recyclability and Recycling

Towards Sustainable Cities

Michael Stacey



WORLD ALUMINIUM

International Aluminium Institute

Nottingham + Llundain

Front cover: 1951 Festival of Britain – Skylon by Powell and Moya, and Dome of Discovery by Ralph Tubbs and Freeman Fox & Partners (John Maltby/RIBA Library Photographs Collection)

ISBN 978-0-9930162-1-9

Published by Cwningen Press 2015

www.s4aa.co.uk

CwningenPress

CP

Aluminium Recyclability and Recycling

Towards Sustainable Cities

Michael Stacey Architects

ATRG ARCHITECTURE + TECTONICS RESEARCH GROUP The University of Nottingham

KIERANTIMBERLAKE

Contents

ONE

introduction

Introduction

Aluminium Recyclability and Recycling is the second report resulting from the Towards Sustainable Cities Research Programme, following on from *Aluminium and Durability*. The objective of Towards Sustainable Cities, 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.

Within this text, when a word or phrase is in bold, it is defined in the Glossary; this occurs on the first entry only.

The **recyclability** of aluminium is a fundamental quality of this light metal and is evidenced in this report, which also examines the **recycling** of aluminium and other building materials. Within architecture, **reuse** is another important aspect of material and resource stewardship; therefore, this too is considered, primarily via case studies.

More than one billion tonnes of aluminium has been produced since 1886, the year the **Hall–Héroult process** was invented. Three-quarters of this metal is still in productive use, a resource that can be considered a material and energy bank for humankind today and in the future. Around 35 per cent is found in buildings, 30 per cent in electrical cables and machinery and 30 per cent in transport applications. Packaging products, because of their relatively short lifetimes, make up less than 1 per cent of aluminium in use, even though this use makes up to 12 per cent of annual metal demand.[1] The aluminium drinks can is the world's most recycled packaging container and can be back in use and on the shelf as another can in as little as six weeks after the previous use.[2] Aluminium is almost infinitely recyclable with no loss of material qualities.[3] Recycling aluminium requires up to 95 per cent less energy than producing aluminium from bauxite.[4]

Whilst reviewing the role of aluminium in the construction of the built environment and how it can be marshalled as an ongoing resource for humankind, it is important to use a clear and effective definition of sustainability. For architecture and the built environment, sustainability is the balancing of economic, ecological, political and cultural objectives within a spatial project.[5] Thus, sustainable development 'seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future', stated Gro Harlem Brundtland in 1987.[6]

A vital component in achieving sustainable development is the resourceful use of materials in delivering products, artefacts and services. The three cornerstones of resourceful material usage are reduce, reuse and recycle. Advances in materials science, digital design and finite element analysis mean that humankind can do more with less, achieving the same or a better level of performance while using less aluminium to form a window section, a curtain-walling mullion or an aluminium structure.[7]

The first mode of reuse in architecture is to find a new use for an existing building, with many humble and high-profile examples throughout the world. The successful reuse of existing buildings offers significant social, environmental and economic benefits for a wide range of architecture typologies, particularly if the energy performance of the existing building stock is improved through, for example, enhanced thermal performance with increased levels of insulation, high-performance double or triple glazing and improved air tightness of the building envelope.[8] The successful delivery of architecture with low **operational energy** requirements increases the importance of the energy of construction embodied in its materials and systems. The social, economic and cultural value of existing buildings including the resource of **embodied energy** has led to the practice of **deep retrofit** or the **reinvention** of architecture. In this process, rather than full **demolition** the original building is stripped back to its basic structure and then reclad, not necessarily following the original footprint, as is evident in the design of the Churchill Centre and the Angel Building, see Chapter Two.[9] These projects technically and aesthetically update the architecture, whilst retaining the performative role and embodied energy of the steel, masonry or concrete elements. Cultural heritage within architecture and infrastructure is now highly valued and has become a global movement, as evidenced by the number of UNESCO World Heritage Sites.[10] Priority is often placed by society on the cultural or heritage value of architecture and infrastructure beyond its original use, be this a former factory or a castle, both of which may have become functionally redundant due to technological change.

The second form of reuse within architecture is the reuse of architecture by relocation; see, for example, the case study in Chapter Four of the Aluminium Centenary Pavilion by Jean Prouvé, which has been located in central Paris on the south bank of the River Seine, then in Lille and is now located back in Paris at Villepinte.

The third form of reuse within architecture is the reuse of building components in a new project; this is primarily associated with structural aluminium components. Both relocation and component reuse suggest a requirement at the design stage for details that are readily or fully reversible, known as **Design for Disassembly [DfD]**.

The final mode for architecture and infrastructure when no longer useful is demolition or disassembly combined with recycling of the building's components and materials. This includes the removal of technologically obsolete glazing systems, which in recent projects has often involved the replacement of corroded steel with aluminium systems offering durability and low-energy performance. The recycling of aluminium is an established and reliable material recovery system with very good collection rates from buildings and infrastructure, aided further by the use of demolition protocols.

It is reasonable to predict that the use of **Building Information Modelling [BIM]** for design and facilities management will facilitate the reuse, relocation and recycling of aluminium architectural components, as data on embedded materials, systems and resources, including specific alloys, will be retained as part of the building information system.

Notes

1 Based on data from 2012. International Aluminium Institute (2014), *Global Aluminium Mass Flow*, London, 2014, available online at www.world-aluminium.org/media/filer_public/2014/06/19/global_aluminium_mass_flow.xlsx (accessed March 2015).

2 Aluminium for Future Generations, *Global Metal Flow*, available online at http://recycling.world-aluminium.org/en/review/global-metal-flow.html (accessed March 2014); *The Future Builds with Aluminium*, http://greenbuilding.world-aluminium.org/home.html (accessed March 2014); Recycle Now, *Cans*, available online at www.recyclenow.com/how_is_it_recycled/cans.html (accessed March 2014).

3 During the recycling process, between 1 and 2 per cent of aluminium by mass is lost, primarily due to oxidisation. As cited in S. K. Das, J. A. S. Green and J. G. Kaufman (2010), *Aluminum recycling: economic and environmental benefits*, Light Metal Age, February, p. 22, available online at www.phinix.net/services/Recycling/Aluminum_Recycling_Economic.pdf (accessed February 2015).

4 European Aluminium Association/Organisation of European Aluminium Refiners and Remelters Recycling Division (2006), *Aluminium Recycling in Europe: The Road to High Quality Products*, EAA/OEA, Brussels, p.6, available online at http://recycling.world-aluminium.org/uploads/media/fl0000217.pdf (accessed April 2014).

5 L. Magee, A. Scerri, P. James, J. A. Thom, L. Padgham, S. Hickmott, H. Deng and F. Cahill (2013), *Reframing social sustainability reporting: towards an engaged approach,* Environment Development Sustainability, 15(1), pp. 225–243.

6 G. H. Brundtland (1987), *Our Common Future: Report of the World Commission on Environment and Development,* United Nations, New York, p. 47, available online at www.un-documents.net/our-common-future.pdf (accessed April 2015).

7 M. Stacey (ed.) (2014), *Aluminium and Durability: Towards Sustainable Cities*, Cwningen Press, Llundain, p. 108.

8 Preservation Green Lab for the National Trust for Historic Preservation (2011), *The Greenest Building: Quantifying the Value of Building Reuse*, NTHP, Washington, DC, available online at www.preservationnation.org/information-center/sustainable-communities/green-lab/lca/The_Greenest_Building_lowres.pdf (accessed February 2015).

9 Deep retrofit of a building typically includes an improvement in energy performance of at least 30 per cent.

10 The United Nations *Convention Concerning the Protection of the World Cultural and Natural Heritage* was agreed in 1972 and the current World Heritage List dates back to 1994 when the World Heritage Committee launched the *Global Strategy for a Representative, Balanced and Credible World Heritage List*. See: United Nations Educational, Scientific and Cultural Organization, *Global Strategy*, available online at http://whc.unesco.org/en/globalstrategy/ (accessed January 2014).

TWO

demolition, reuse and recycling

Demolition, Reuse and Recycling

This chapter uses case studies, design guides, protocols and available data to examine why buildings are demolished and the potential environmental savings offered by the recycling of construction materials, in particular aluminium, after demolition. This chapter also looks at the use of aluminium to improve building performance with respect to environmental impact and to minimise redundancy and thus demolition of existing building stock.

Life Expectancy of Buildings

Typically, architecture and infrastructure, with their significantly lengthy **life expectancy**, represent long-term investments of resources and materials. In the briefing stages of a building design, a building's life expectancy is normally related to the typology. Using the UK as an example, guidance is provided by BS 7543: 2003 *Durability of Buildings and Building Elements, Products and Components*, for a typical range of typologies.[1]

Category	Design service life for building	Examples
Temporary	Up to 10 years	Site huts; temporary exhibition buildings
Short life	Min. 10 years	Temporary classrooms; warehouses
Medium life	Min. 30 years	Industrial buildings; housing refurbishment
Normal life	Min. 60 years	Health, housing and educational buildings
Long life	Min. 120 years	Civic and high-quality buildings

Table 2.1 Design service life for building from BS 7543: 2003

In the USA, the median lifetime for commercial buildings is between 70 and 75 years, as calculated by the Pacific Northwest National Laboratory for the US Department of Energy (2010).[2] The median age of all buildings in the USA is 56.5 years.[3]

Actual life expectancy does not necessarily relate to typology. A much-loved cottage, for example, may far exceed its original intended life expectancy by careful maintenance, or a project may be swept prematurely away by change in land use or spatial redundancy. The Organisation for Economic Co-operation and Development [OECD] estimates that over 50 per cent of the current global building stock will still be standing in 2050.[4]

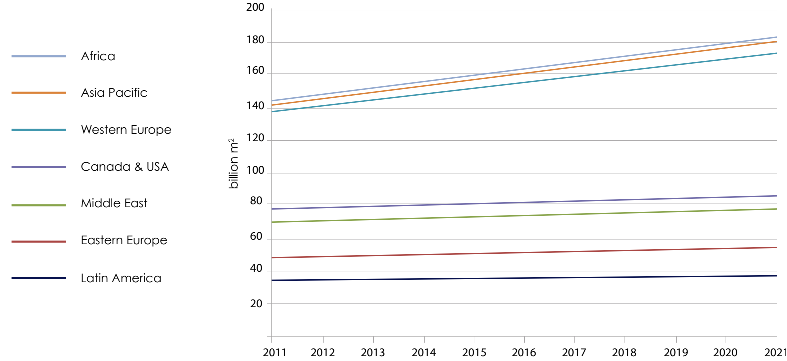


Fig. 2.1 Building stock by region, world markets: 2011–2021 (based on Pike Research 2012)

Architecture and infrastructure typically has a long in-use phase and the global building stock continues to grow. It is predicted that the total global building stock will grow from over 140 billion m^2 in 2011 to over 180 billion m^2 by 2021. China will dominate this growth in building stock, where an estimated 2 billion m^2 will be added each year. North America and Europe together represent a significant percentage of the global building stock, as shown in Figure 2.1.[5] In essence, the reservoir or energy bank of aluminium in use in architecture and infrastructure will continue to grow as the twenty-first century progresses.

This growth in building stock reflects the fact that, since 2008, over half of the world's population lives in cities.[6] The current world population of 7.2 billion is projected to increase by 1 billion over the next 12 years and reach 9.6 billion by 2050, according to the United Nations.[7]

Fig. 2.2 Vague Formation, a mobile music pavilion designed by soma has an extruded aluminium structure

In comparison to buildings and aluminium-based building components, the typical in-use life expectancy of an aluminium drinks can is six weeks, before being recycled into a new can. The average life expectancy of a car before recycling in the USA went up from 9.8 years in 2002 to about 11.4 years in 2013.[8] Design quality is highly valued within the realm of car production and ownership. Mark White, Director of **Lightweighting** for Jaguar Land Rover, observes that '85 per cent of Land Rovers and Range Rovers that have ever been made are still on the road, with most of them actually being used for off-road use'.[9]

Vitra, the manufacturer and distributor of high-quality modern furniture including the Aluminum Group chairs designed by Charles and Ray Eames, views design quality as a fundamental wellspring of sustainability.[10] One of Vitra's primary goals, in terms of sustainability, is to 'make durable products with a long lifespan, both in terms of function and aesthetics'.[11] For more information on the Aluminum Group chairs, see Chapter Four.

Demolition

The noun 'demolition' is defined as 'the action or process of demolishing' based on the verb 'demolish' defined as 'pull or knock down (a building)'.[12] From the apparently simple starting point of the action or process of pulling or knocking down (a building), a complex and evolving picture of demolition and contemporary best practice emerges.

Why Are Buildings Demolished?

Typically, a building is demolished because it is:

- unfit for purpose;
- a dangerous structure, due to a lack of maintenance, fire, earthquake or warfare;
- spatially inappropriate – either too small and difficult to extend or the space is required by road or rail, either new build or widening;
- affected by a significant change in urban land use;
- technically obsolete – services appear to be a stronger driver in this area than energy and comfort;
- programmatically obsolete – for example, the relocation of industry due to the invention of the shipping container;
- politically unacceptable – symbolic of a different future.

With the exceptions of dangerous structures and catastrophic events, the decision to refurbish, relocate or demolish tends to be driven by a combination of these factors.

Within the UK housing sector, 'historically, the highest level of demolition occurred between 1961–75, when the annual rate was just over 81,000 per annum … the majority being defined as unfit. Only 20% of those demolished between 1996–2004 were considered to be unfit (EHCS 2001), indicating a shift in the criteria used to decide which properties are removed from the stock.'[13]

Fig. 2.3 Tower block in Lenton, Nottingham, being demolished

Demolition and Mitigation of Waste

Since landfill taxation was introduced in California in 1989 and in the UK in 1996, a significant body of research has been conducted into the mitigation and minimisation of waste from demolition and new-build construction. In 2003, the UK's Institution of Civil Engineers developed a protocol to encourage the minimisation of waste from regeneration projects. This has been developed further into the current ICE Demolition Protocol (2008),[14] a guide to decision making when evaluating existing buildings, in terms of waste minimisation. This protocol encourages an early audit of existing buildings under consideration, either for **refurbishment** or demolition, if appropriate, identifying the potential for the reuse of specific components or the recycling of demolition materials. Typically, this should be undertaken as early as possible in the demolition/refurbishment process, forming a part of an initial Feasibility study leading to the development of a Site Waste Management Plan [SWMP].[15] For more detail and proposed timings beyond the Feasibility stage, see Table 2.2.

The flowchart in Figure 2.5, based on the ICE Demolition Protocol, proposes the following decision-making process:

1. Evaluate the reuse of an existing building;
2. Evaluate for disassembly or **deconstruction**;
3. Consider demolition and material recovery as the final option.

Fig. 2.4 Building scrap, including aluminium building components

A summary of decision making to minimise waste from redevelopment at either the Feasibility or the Outline Design stage is shown in Table 2.2. This protocol includes an approach to delivering Materials Resource Efficiency [MRE] that maximises reuse and recycling.

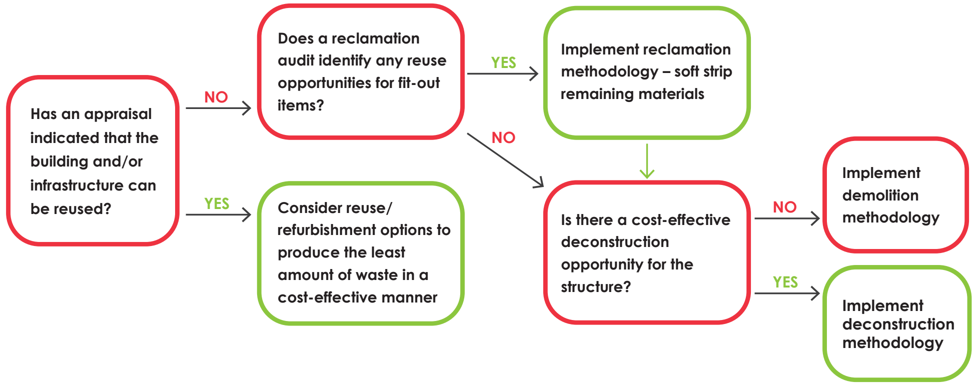


Fig. 2.5 Flowchart of decision-making steps for assessing a sustainable approach to redevelopment, based on ICE Demolition Protocol (2008)

Consideration	**Stage**	**Mechanism**	**Outcome** (which demonstrates viability)
Building / infrastructure reuse	Feasibility	Design and cost appraisal	Space, integrity, aesthetics, and refurbishment costs satisfactory
Reclamation of internal/fit-out products	Outline Design	Design and reclamation audit to assess potential for recovering internal/fit-out products for reuse	Opportunities for reuse in situ and off site identified, including good market potential
Deconstruction	Outline Design	Audit to assess the potential of the structure for reuse	Elements of structure identified that can be reused in situ or off site identified, including good market potential
Demolition	Outline Design	Pre-demolition audit to assess recycling options	Recovery targets for recycling, in situ and off site set

Table 2.2 Summary of decision making to minimise waste from development, based on ICE Demolition Protocol (2008)

Reuse

Disassembly or Deconstruction

Demolition

Fig. 2.6 Consider reuse before disassembly or deconstruction, with demolition and material recovery being the final option

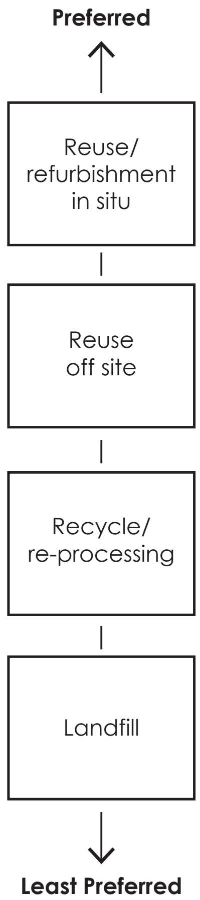


Fig. 2.7 Delivering materials resource efficiency [MRE] for materials and components

Fig. 2.8 Demolition of concrete-framed building, Edinburgh, photographed December 2014

Fig. 2.9 Demolition of Heathrow Terminal 2, September 2010

Michael Stacey Architects' approach to the design of a new Ballingdon Bridge for Suffolk County Council, completed in 2003, was based on a thorough understanding of sustainability and its place in the reconstruction of a major piece of infrastructure, a trunk road bridge. The feasibility of repairing the existing concrete bridge from 1911 was evaluated, but this was not possible as its foundations were failing under the load of 42-tonne trucks, the current European Union standard articulated lorry weight.[16] Ballingdon Bridge was designed with Arup and rebuilt by Costain under a non-adversarial partnering contract. This facilitated the recycling of both the aggregate and mild steel reinforcement of the old bridge. Although this only achieved a modest credit to the contract, the primary purpose was to minimise waste and the use of landfill. The recycled concrete aggregate became Type 1 fill under a road in Essex.[17] At Ballingdon Bridge, there was no site area to accommodate the stockpiling of material, as encouraged by the ICE Demolition Protocol; therefore the recycled concrete aggregate could not be reused to form new in situ concrete to tie the precast concrete bridge units together to form a monolithic structure, although this was considered. The site of Ballingdon Bridge is both tightly urban and a high-quality river landscape that is a Site of Special Scientific Interest [SSSI].

Fig. 2.10 The new Ballingdon Bridge designed by Michael Stacey Architects

In essence the ICE Demolition Protocol proposes a return to resourcefulness in construction, including reuse, **reclamation** and bricolage, see below. Although the emphasis in initiatives such as the ICE Demolition Protocol is on the waste minimisation of construction materials such as gypsum wallboard going to landfill, the process is useful for all materials, including aluminium, as it encourages early decision making and clarity of ownership of recovered components and demolition materials.

Fig. 2.11 Reconstruction of Ballingdon Bridge on a tight urban site – the temporary Bailey Bridge being lifted into place

Fig. 2.12 The 1911 Ballingdon Bridge being demolished in 2002, with both the concrete and mild steel reinforcement about to be recycled

Fig 2.13 The New Bodleian Library is a Grade II listed building, refurbished by Wilkinson Eyre Architects, and reopened in 2014

The refurbishment of the New Bodleian Library, a Grade II listed building, by Wilkinson Eyre features in *Aluminium and Durability*, the first report in the Towards Sustainable Cities Research Programme.[18] All of the major features of Giles Gilbert Scott's original architecture were retained during refurbishment, including the 77-year-old anodised aluminium windows. In order to make the library fit for purpose in the twenty-first century, Wilkinson Eyre has organised a major internal refurbishment of the 11 floors of the library, three of which are underground. Once this £50 million project is complete, in the context of central Oxford the library will appear unchanged. The construction waste and recycling streams for this project are:

- 6,500 tonnes of concrete;
- 80 tonnes of asbestos;
- 1,000 tonnes of steel;
- 260 tonnes of general waste;
- 140 tonnes of salvaged stone;
- 81km of shelving removed from the stacks;
- 3km of shelving removed from the reading rooms and the office.

This took over 170,000 worker hours over a period of 12 months. Upon its reopening in March 2015, the New Bodleian Library was renamed the Weston Library in honour of its primary sponsor.

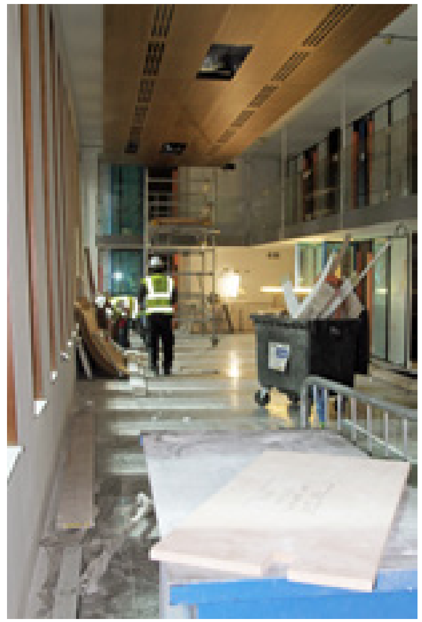


Fig 2.14 The refurbishment of the New Bodleian Library

Demolition Data

There is little statistical data on the reasons why buildings are demolished, 'at least in North America', observes Wayne Trusty of the Athena Institute.[19] Furthermore, there appears to be no systematic collection of data on demolition in many countries. Between 2000 and 2003, the Athena Institute undertook a survey of the demolition of 230 commercial and residential properties in St Paul, Minnesota. This research included the age of the building, the main structural material and the reasons for demolition. Figure 2.15 shows a summary of reasons for demolition of these buildings.

More than half of the buildings demolished were over 76 years old and 70 per cent between 51 and over 100 years old, with only 6 per cent aged between 1 and 25 years. Unfortunately for the purposes of this report, the presence of aluminium was not recorded. The research confirmed the vernacular construction of the USA in nineteenth and twentieth centuries in that two-thirds of the buildings demolished were constructed of timber.

The order of magnitude of demolition and replacement with new buildings in the USA is cited as over 85 million m^2 per annum by Preservation Green Lab in its report for the National Trust for Historic Preservation [NTHP], *The Greenest Building: Quantifying the Value of Building Reuse*;[20] however, this is based on US Environmental Protection Agency [EPA] data from 1996.[21] A US forecast by the Brookings Institution also predicted that 'some 82 billion square feet (over 7.5 billion m^2) of existing space will be demolished and replaced between 2005 and 2030 – roughly one-quarter of today's existing building stock'.[22]

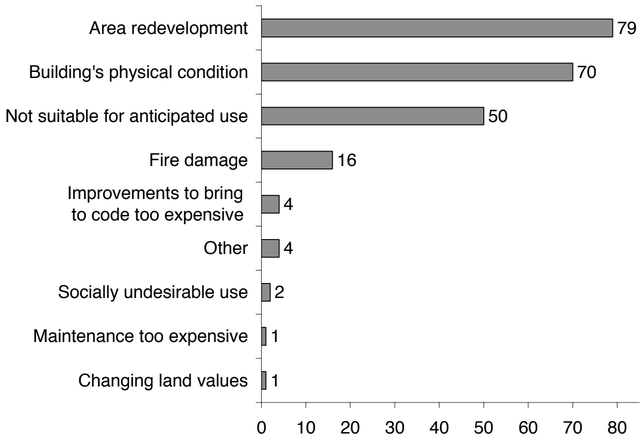


Fig. 2.15 The Athena Institute undertook a major survey of buildings demolished in St. Paul, Minnesota, for the period from 2000 to mid-2003

Construction Heritage and Embodied Energy

The rise of interest in construction heritage dates back to the mid-nineteenth century. However, this became much more significant after 1972, when the UN *Convention Concerning the Protection of the World Cultural and Natural Heritage* was agreed.[23] This has emphasised the value of retention and the need for the reinvention of architecture and building fabric rather than demolition.

A further argument against demolition is the need to maximise the performative role of the embodied materials and energy invested in the existing building fabric, minimising waste and achieving significant energy and greenhouse gas savings. The potential benefits of an increased reuse of existing buildings are clearly articulated in *The Greenest Building: Quantifying the Value of Building Reuse*. This report covers four climatic regions in the USA:

1. Portland;
2. Phoenix;
3. Chicago;
4. Atlanta.

It also covers six building typologies:

1. single-family homes (detached);
2. apartment buildings;
3. offices;
4. urban mixed-use buildings;
5. schools;
6. warehouse conversions.

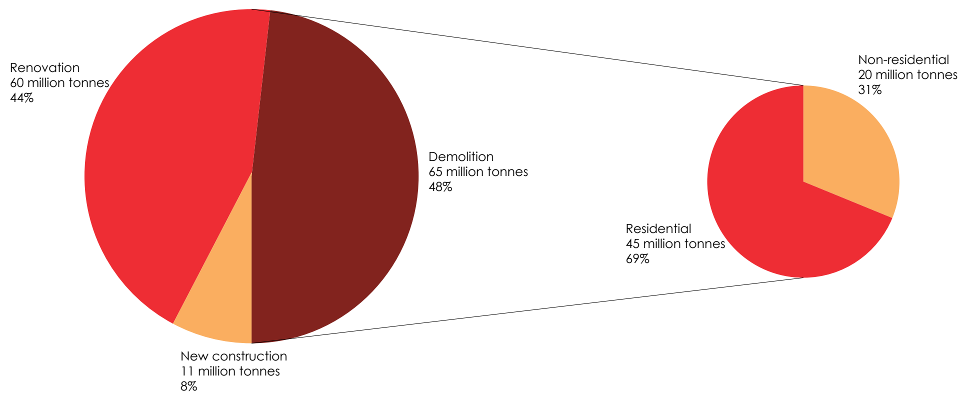


Fig. 2.16 Construction and demolition waste, and recycling stream, from the University of Florida Powell Center for Construction & Environment (based on EPA data 1996)

Using a robust **Life Cycle Assessment [LCA]** methodology based on European materials data,[24] the report shows that the reuse and **retrofit** of existing building stock can achieve significant energy savings – equivalent to the operational energy requirement of a similar new building over 10 to 80 years, depending primarily on typology. Preservation Green Lab observe:

> Reuse-based impact reductions may seem small when considering a single building. However, the absolute carbon-related impact reductions can be substantial when these results are scaled across the building stock of a city. For example, if the city of Portland was to retrofit and reuse the single-family homes and commercial buildings that it is otherwise likely to demolish over the next 10 years, the potential impact reduction would total approximately 231,000 metric tonnes of CO_2 – approximately 15% of their county's total CO_2 reduction target over the next decade.[25]

This report also clearly calls for more incentives for the enhancement of the thermal performance of the building stock in the USA. It does note, however, that in some conversion typologies – especially warehouse to residential – the amount of material required to achieve this spatial conversion means that in such cases a new-build apartment building of the same size and similar thermal performance will have a lower environmental impact. Therefore the retention of existing fabric should always be considered, but needs to be evaluated by the design team on a site- and typology-specific basis. In this report, Preservation Green Lab also observe that the materials selected for a retrofit are of vital importance to maximising the benefits of reusing buildings, and this needs to be researched further.

Demolition of Tall Buildings

Fig 2.17 [top] Metropolitan Life Building, designed by Napoleon LeBrun and Sons, New York, completed in 1909

Fig 2.18 [above] Singer Building, architect Earnest Flagg, completed in 1908 and demolished in 1968

While there is a general lack of systematically collected data on the demolition of buildings globally, such data is available for tall buildings. The Council on Tall Buildings and Urban Habitat [CTBUH], founded in 1969, maintains a robust database of tall buildings over 150m high throughout the world. The oldest extant tall buildings or skyscrapers of this height are in North America, all from the first two decades of the twentieth century:

- Metropolitan Life Building, New York, 1909;
- 14 Wall Street, New York, 1912;
- Woolwich Building, New York, 1913;
- PNC Tower, Cincinnati, 1913.

Between 1909 and 2015, 749 tall buildings over 150m high have been built in North America. Of these skyscrapers, only seven have been demolished (only 1 per cent of the total skyscrapers built), with three of these in the tragic events of 11 September 2001: the Twin Trade Towers designed by Minoru Yamasaki & Associates, completed in 1972, and 7 World Trade Centre designed by Emery Roth & Sons, completed in 1987.

The four other tall buildings over 150m high that have been demolished are:

1. the Singer Building, New York, designed by Earnest Flagg, completed in 1908 and demolished in 1968;
2. the Morrison Hotel, Chicago, completed in 1925 and demolished in 1965;
3. Deutsche Bank, New York, designed by Shreve, Lamb & Harmon Associates, completed in 1974 and demolished in 2011;
4. One Meridian Plaza, Philadelphia, designed by Vincent Kling & Associates, completed in 1972 and demolished in 1999.[26]

Throughout the rest of the world, not a single skyscraper over 150m high has been demolished. Table 2.3 records the earliest project for each region and the number of buildings completed. Globally, there are 3,262 skyscrapers over 150m high.

Therefore, only four tall buildings of this height in the world have been subject to planned demolition. The average age of these buildings upon demolition was 40 years; however, the sample is very small. Of the extant tall buildings of this height, the oldest is 106 years and the average age is over 30 years, on publication of this report.[27]

Based on CTBUH data, Patterson and colleagues have suggested that the service life of a tall building should be considered to be at least 100 years.[28] In their paper, the authors observe that '**renovations** will be required during the life time of the building' and a clear life cycle target for the curtain-walling system should be established during the design stage.[29] Furthermore, they conclude: 'The durability of materials and systems requires priority consideration early in the design process. The service life of all materials, products and system components must be identified and matched to the targeted lifespan.'[30]

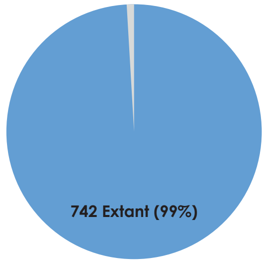


Fig. 2.19 North America tall buildings 1885–2015, showing quantity of Tall Buildings over 150m high completed with only 1% demolished (7) and 99% extant (742), based on CTBUH data early 2015

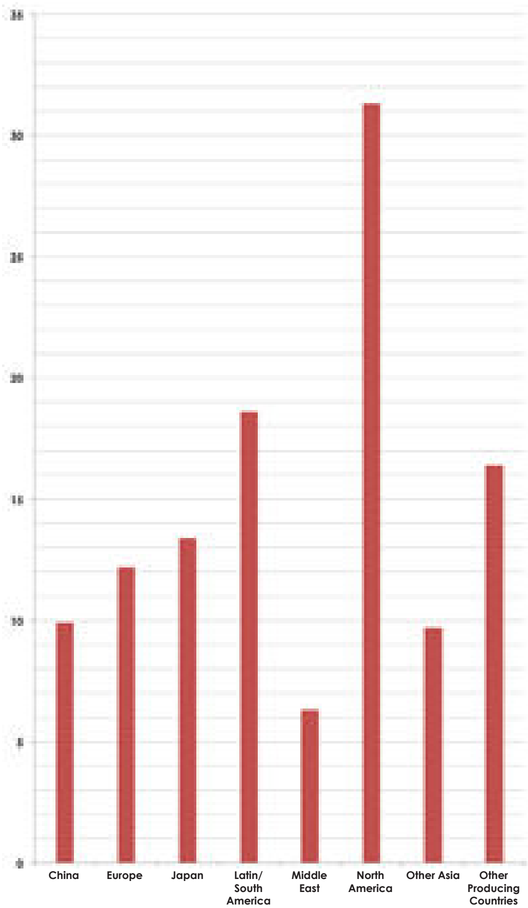


Fig 2.20 Average age of tall buildings over 150m globally by region, early 2015 (not including under construction)

Region	Completed Projects	Extant %	Demolished %	Earliest Extant Tall Building
China	1101	100%	0%	Jardine House, Hong Kong, 1973; Agricultural Bank of China Tower, Changsha, 1984 (Mainland China)
Europe	119	100%	0%	Palace of Culture and Science, Warsaw, Poland, 1955
Japan	190	100%	0%	Kasumigaseki Building, Tokyo, 1968
Latin/South America	45	100%	0%	Altino Arantes, São Paulo, Brazil, 1947
Middle East	259	100%	0%	Baynunah Hilton Tower Hotel, Abu Dhabi, United Arab Emirates, 1994
North America	749	99%	**1% (7 Projects)**	Metropolitan Life Building, New York, 1909
Other Asia	487	100%	0%	MVRDC, Mumbai, India, 1970
Other Producing Countries	121	100%	0%	Kotelnicheskaya Naberezhnaya, Moscow, Russia, 1952; Australia Square Tower, Sydney, Australia, 1967

Table 2.3 Earliest extant tall buildings over 150m high by region including quantity of buildings completed and percentage demolished, based on CTBUH data early 2015

Professor Douglas Noble, together with PhD candidates Andrea Martinez and Mic Patterson, at the University of Southern California, are working on *facaderetrofit.org*, a web-based resource for building façade retrofit that includes a database of international façade retrofit projects. This research is funded in part by a grant from the CTBUH, sponsored by ECADI. At the time of writing, the database is in beta testing and is scheduled for public launch in the summer of 2015. This research should establish a much clearer picture of the timescales for the replacement of windows and curtain walling in many parts of the world.

The timescales for the replacement of windows and curtain walling for selected projects in North America are examined later in this chapter.

Key Strategies for Retrofit and Reuse

There are primarily three strategies for retrofit and reuse that retain the existing building fabric yet enhance the performance, often bringing a new purpose to the existing architecture:

1. **Technical updating of the building envelope** – for example, the single-glazed stainless-steel curtain walling of Lever House, Park Avenue, New York, by Skidmore, Owings & Merrill, being replaced with high-performance thermally broken aluminium curtain walling;
2. **Over-cladding** – for example, Parsons House, London;
3. **Reinvention or deep retrofit** – typically stripping back to the structural frame such as with the Churchill Centre, Rotterdam, by Brookes Stacey Randall Fursdon or the Angel Building, London, by AHMM, combined with significantly enhanced thermal performance, achieving at least a 30 per cent reduction in operational energy requirement.

In all of these strategies, the metal components within the existing building that are removed become available for recycling, although a significant proportion of the embodied energy of the building fabric is saved. Case studies of all three strategies are set out later in this chapter.

Fig. 2.21 Lever House, designed by Skidmore, Owings & Merrill

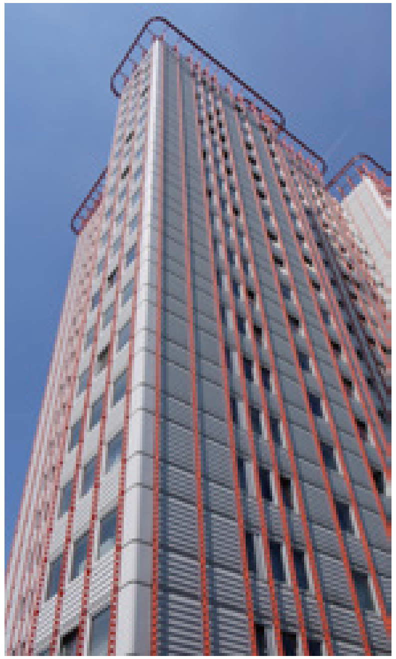


Fig. 2.22 Parsons House over-cladding, designed by Peter Bell & Partners

Fig. 2.23 Churchill Centre, architect Brookes Stacey Randall Fursdon

Collection Rates for Aluminium

The 2004 TU Delft study *Collection of Aluminium from Buildings in Europe*, commissioned by the European Aluminium Association, remains the only systematic study on the collection of aluminium from demolished buildings.[31] It demonstrates collection rates for aluminium at demolition of between 92 and 98 per cent.

A relative criticism of this study is that the age of the buildings when demolished was in some cases either not recorded or not known. Within the table opposite the author has added the date of construction when this data is separately available; for example, the aluminium roof of the first Wembley Stadium was installed in 1963, whilst the stadium opened in 1923. It is interesting to observe that the demolition of 1920s terraced housing in the Netherlands yielded significant aluminium scrap, although not all of it was part of the original construction; this included aluminium components such as kitchen sinks and carpet trims.

Small objects account for most of the aluminium lost typically to landfill during disassembly and demolition, as shown by the apartment building in Le Mans, France, which had a collection rate of only 31 per cent due to all of the aluminium being in small parts. Disassembly of small parts is considered by many to be uneconomic because labour costs during collection swiftly exceed the metal value.[32]

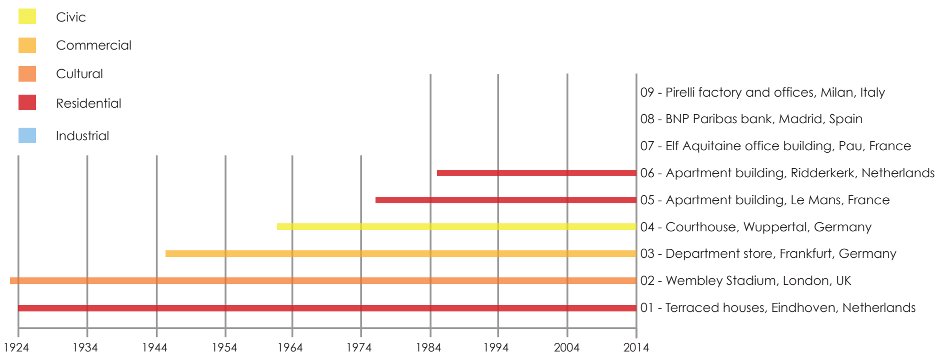


Fig. 2.24 Graph showing the age and typology of buildings included in the TU Delft Study, *Collection of Aluminium from Buildings in Europe* (2004)

No	Building	Date of construction	Aluminium content grams per tonne of demolition waste	Collection rate (%)	Aluminium applications
1	213 terraced houses, Eindhoven, Netherlands	1920s	49	95	Sinks, roof strips and chimneys
2	Wembley Stadium, London, UK	1923 (aluminium from 1963 renovations)	6,100	96	By mass 87% of aluminium scrap collected came from the roof sheets, with 13% from windows, doors and smaller components
3	Department store, Frankfurt, Germany	1945	1,750	98	Interior aluminium retail fit-out, lighting, air-conditioning tubes, cable casings, windows, doors and exterior panelling
4	Courthouse, Wuppertal, Germany	Early 1960s	7,500	98	Windows and exterior cladding
5	Apartment building, Le Mans, France	1971	18	31	Small aluminium parts, e.g., door handles
6	272 apartments, Ridderkerk, Netherlands	1970s	31	95	Door and window grips, door thresholds, draught prevention strips and strips around windows
7	Elf Aquitaine Office, Pau, France	_	640	92	By mass 67% of aluminium scrap was cladding and 13% solar shading
8	Pirelli factory and offices, Milan, Italy	_	430	94	By mass 40% was aluminium windows and 17% internal ceilings; remaining aluminium scrap from duct pipes, partition walls and door frames
9	BNP Paribas bank, Madrid, Spain	_	4,000	95	Cladding, windows and ducts

Table 2.4 Summary of case studies from *Collection of Aluminium from Buildings in Europe* (2004)

WRAP is a UK-based organisation working with the UK, European and local governments to promote recycling, including the recycling of demolished buildings. It does not specifically study and record the flow of scrap aluminium from demolished buildings in the UK as it considers this a mature market with a technologically stable basis. Within North America, a very similar approach is taken and few records are kept of the recycling rates from construction and demolition, as the recycling of aluminium is perceived as an established technology with high collection rates driven in part by economic value and demand from the open market. In a waste diversion study undertaken for the Chicago Department of Environment in 2010, led by consultants CDM, it was found that 99 per cent of aluminium scrap was successfully collected for recycling from the construction and demolition sector in the Chicago metropolitan area, compared to 95 per cent in neighbouring King County.[33] This was based on data from 2007. The rates are on a direct par with the TU Delft study. Furthermore, CDM observed that there is little or no scope to improve the recycling rates of aluminium beyond 99 per cent and thus increase this aspect of waste diversion in Chicago.

Waste Diversion and LEED

The Leadership in Energy and Environmental Design [LEED] environmental assessment tool was developed in 2000 by the US Green Building Council and based on BREEAM. At the time of writing, the current version is LEED v4, issued in 2014. Under LEED v4, buildings are certified to four levels:

1. Certified: 40–49 points;
2. Silver: 50–59 points;
3. Gold: 60–79 points;
4. Platinum: 80 points and above.

To encourage the diversion of construction and demolition waste from landfill, LEED provides credit for waste diversion. To achieve this credit, a design and construction team must develop a waste management plan and track waste leaving the construction site, documenting the quantities. Under LEED, 89 per cent of buildings have achieved credit for waste diversion – some 23,000 projects.[34] The use of the ICE Demolition Protocol and a SWMP can be used as evidence of waste minimisation for LEED, BREEAM, Code for Sustainable Homes [CfSH] and Ecohomes in Scotland.

Harvard University decided to make its renovation of 46 Blackstone, the former works of the Cambridge Electric Light Company with its buildings dating from 1926 and 1929, and an earlier dairy building on site since 1889. The architects have presented an ecologically well-informed response. These existing buildings, on the south side of the Cambridge Campus, were converted to over 3,700m^2 of office to a design by Bruner Cott & Associates. Completed in 2006, this project was the first at Harvard to achieve LEED Platinum, in part by diverting over 99 per cent of construction and demolition waste, by mass, from landfill via an implemented SWMP.[35]

Many states in the USA have developed waste reduction protocols and implemented them into code both for environmental and economic reasons. A good example is the *Massachusetts 2010–2020 Solid Waste Master Plan: Pathway to Zero Waste* (April 2013).[36] This plan notes the value of recycling, even allowing for the collection and delivery of scrap: 'For example, the greenhouse gas benefits of recycling aluminum instead of disposing of it are so large that you would need to transport aluminium about 116,000 miles by truck before the GHG emissions from this transportation would equal the GHG emissions avoided by recycling that aluminum.'[37] Orange County in North Carolina is an example of a local government that has passed a law on recycling. It has implemented the *Regulated Recyclable Material Ordinance* (2002), regulating which materials must be recycled, including all scrap metals.[38]

In the case studies researched for Chapter Four, all of the demolished projects feature the successful recycling of the aluminium components, even if this occurred over 60 years ago.

Fig. 2.25 The LEED Platinum Harvard University Blackstone Offices, Cambridge, MA, architect Bruner Cott & Associates, completed in 2006

Global Aluminium Flow

In 1906, when Otto Wagner completed the Postsparkasse, the annual global production of aluminium was 6,000 tonnes; by 2014, this had reached an annual total of 53 million tonnes of aluminium.[39]

More than one billion tonnes of aluminium has been produced since 1886, the year the Hall–Héroult **electrolysis** process was invented. Three-quarters of this metal is still in productive use – a resource that can be considered to be a material and energy bank for humankind today and in the future. Around 35 per cent is found in buildings, 30 per cent in electrical cables and machinery and 30 per cent in transport applications. Packaging products, because of their relatively short lifetime, make up less than 1 per cent of aluminium in use, although they constitute 12 per cent of annual metal demand.[40] The aluminium drinks can is the world's most recycled packaging container and among the most recycled products. It is typically back in use and on the shelf as another can in as little as six weeks after the previous use.[41] The International Aluminium Institute [IAI] has developed detailed aluminium mass flow models.[42] The potential release of aluminium to recycling from architecture and the built environment is set out in Chapter Five.

The primary energy consumed globally in the production of primary aluminium in 2013 was 5 million TJ, predominantly in the forms of electricity generation or power mix (including hydro electric and coal fire power station) as shown in Figure 2.29.[43] The energy required by each of the unit processes, from bauxite mining to ingot casting is shown in Figure 2.26. Smelting, consuming approximately 50 per cent of the required primary energy, has been a focus for process improvements. The energy required to

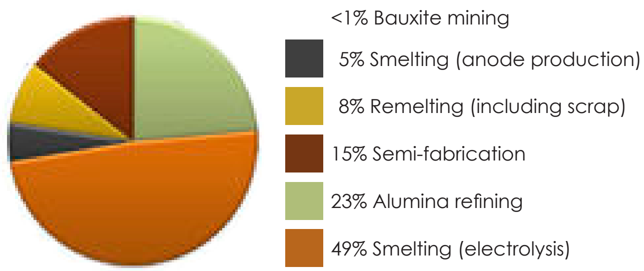


Fig. 2.26 Global aluminium industry energy use required to produce primary aluminium by stage, 2013

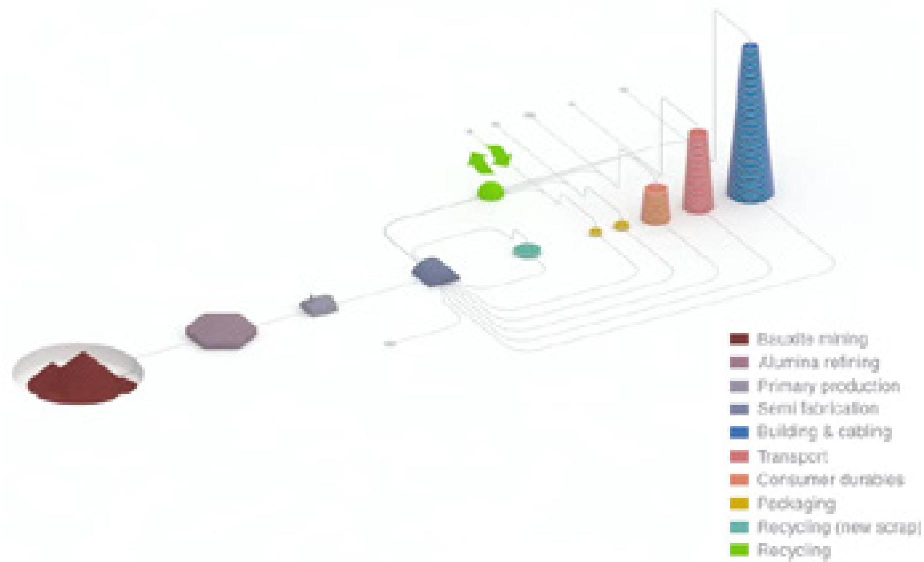


Fig. 2.27 Diagram of global aluminium flow

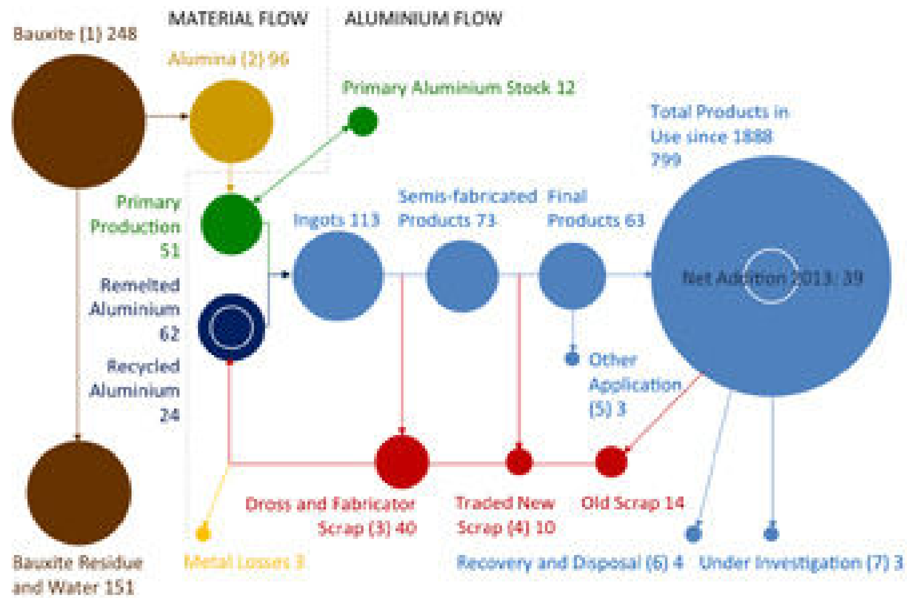


Fig. 2.28 IAI Global Mass Flow 2013 (quantities in million tonnes)

produce primary aluminium has been reduced significantly over the past 20 years with a 15 per cent reduction in electrical energy used in the smelting process.[44] Similarly, the energy required by the **Bayer process**, invented and patented in 1887 by Austrian scientist Karl Josef Bayer, which is the most commonly utilised industrial process for extracting alumina from bauxite ores, has also seen a significant reduction in the energy required.[45] The IAI set a voluntary objective of a 10 per cent improvement in energy intensity in alumina processing between 2006 and 2020, with 13 per cent having already been achieved in 2013.[46]

Based on IAI's *Environmental Metrics Report 2014*, reporting 2010 data, the primary energy required to produce a kilogram of aluminium ingot is 190MJ including China and 153MJ excluding China.[47]

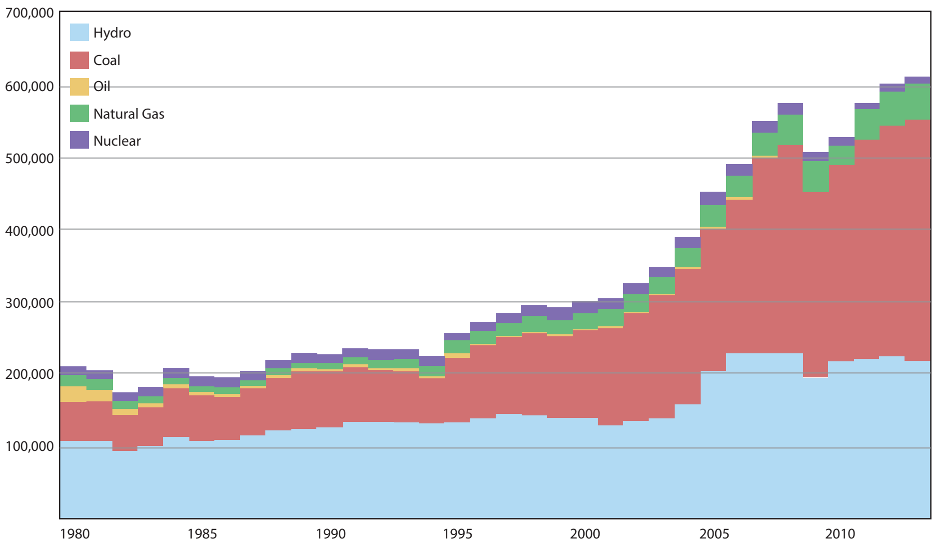


Fig. 2.29 World **power mix** used to produce aluminium reported between 1980–2013 (GWh)

Infinitely Recyclable

Aluminium is almost infinitely recyclable with no loss of material qualities. Based on a collection rate of 95 per cent and a process loss of 2 per cent combined with a mean service life of 60 years, aluminium building components are theoretically recyclable for over 3,000 years. As observed above, architecture and infrastructure typically represent long-term uses of aluminium. The environmental impacts of components and products used in construction, including energy use and savings, should be assessed on **cradle-to-grave** basis.

Each tonne of aluminium recycled avoids approximately 9 tonnes of CO_2e. Globally, the recycling of aluminium avoids over 100 million tonnes of CO_2e per year.[48] The potential availability of aluminium scrap from architecture and the built environment over time, and the resultant savings in CO_2 emissions, is discussed in further detail in Chapter Five.

Fig. 2.30 Closing the loop of material flow by reuse and recycling

Closing the Loop of Material Flow

The *OECD/IEA Joint Workshop on Sustainable Buildings: Towards Sustainable Use of Building Stock* stressed that 'the shift of mind-set, from traditional ways of perceiving the building process as linear (e.g., building from virgin materials and ending with demolition) to circular thinking (e.g., closing the loop of material flow), is necessary to improve the sustainability of the building sector'.[49] Based on the findings of the Towards Sustainable Cities research, aluminium scrap has been consistently recovered from buildings upon demolition or disassembly, typically with only small items such as window catches going to landfill, mingled with other materials. The inherent recyclability of aluminium facilitates a closed-loop material flow.

Not only is there a need to conceive of the built environment as a system set in the context of time and ecology, there is also a need to view materials objectively rather than from an ideological standpoint. All building is an alliance of materials, each with a performative role within the constructive details of architecture and infrastructure. Life Cycle Assessment [LCA] is one means of modelling the embodied impacts of a material, product or whole building assembly, and provides a more rounded view of the impacts of materials than headline embodied energy figures.

Globally around 25 million tonnes, or 30 per cent of global aluminium demand, is met from recycled sources.[50] The use of recycled aluminium in Europe is broadly consistent with this global figure.[51]

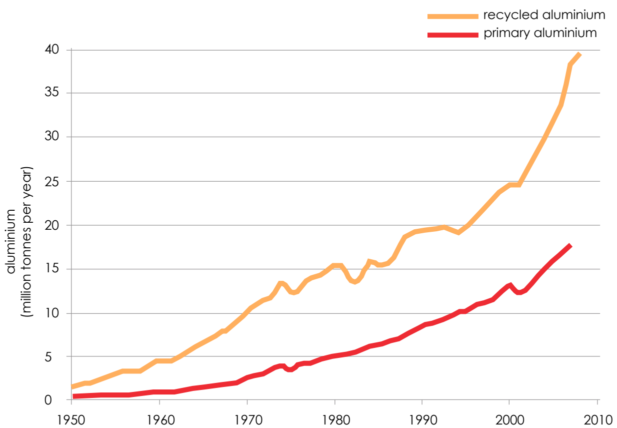


Fig. 2.31 The growth of primary production of aluminium and recycled aluminium (based on IAI data 2009)

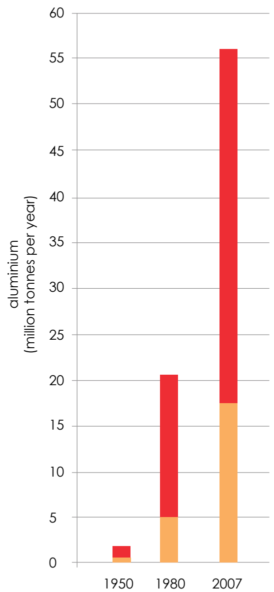


Fig. 2.32 Global use of primary and recycled aluminium in 1950, 1980 and 2007 (based on IAI data 2009)

Life Cycle Assessment [LCA]

The International Organization for Standardization [ISO] defines LCA as the assessment of the environmental impact of a given product throughout its lifespan.[52] The ISO 14040 series was established in the early 1990s to standardise LCA methodologies. These international standards describe the principles and framework behind LCA and define each of the phases and steps involved in conducting an LCA. A useful introduction to assessment methods has been written by Kathrina Simonen.[53]

LCA standards (ISO 14040, 14044, 14025, 21930 and CEN 15804) provide a clear methodology and are intrinsically flexible, unlike prescriptive standards. However, this has resulted in a diversity of terms being applied to key stages in the methodology within LCAs. Menzies and colleagues have called for consistency in terminology, arguing that 'a standard language for defining the materials, products, processes, objectives and methodologies of studies and other LCA terms, is crucial'.[54] This is particularly important to specifiers, including architects and engineers. Therefore, this book includes a glossary that defines key terms used within the text, including the terminology of LCAs.

Within an LCA, there are two approaches to assessing the benefits of recycling:

1. the **recycled content method**;
2. the **end-of-life recycling method**.

The recycled content method looks back to where a material was sourced, and provides a measure of waste diversion. This approach is based on a waste management perspective, where the general aim is to promote a market for recycled materials that is otherwise limited, uneconomic or underdeveloped. In 2006, all of the metals industries, from aluminium to zinc, recommended the end-of-life recycling method as the most appropriate for materials that fully maintain their material qualities when recycled time and time again.[55] The end-of-life recycling method is based on a product life cycle and material stewardship perspective. It considers the fate of products after their use stage and the resultant material output flows.[56]

The third report in the Towards Sustainable Cities Research Programme, *Aluminium and Life Cycle Thinking*, written by Carlisle, Friedlander and Faircloth, compares LCAs for a range of window frame materials – aluminium, wood, aluminium-clad wood and PVCu – using both the recycled content method and the end-of-life recycling method.[57]

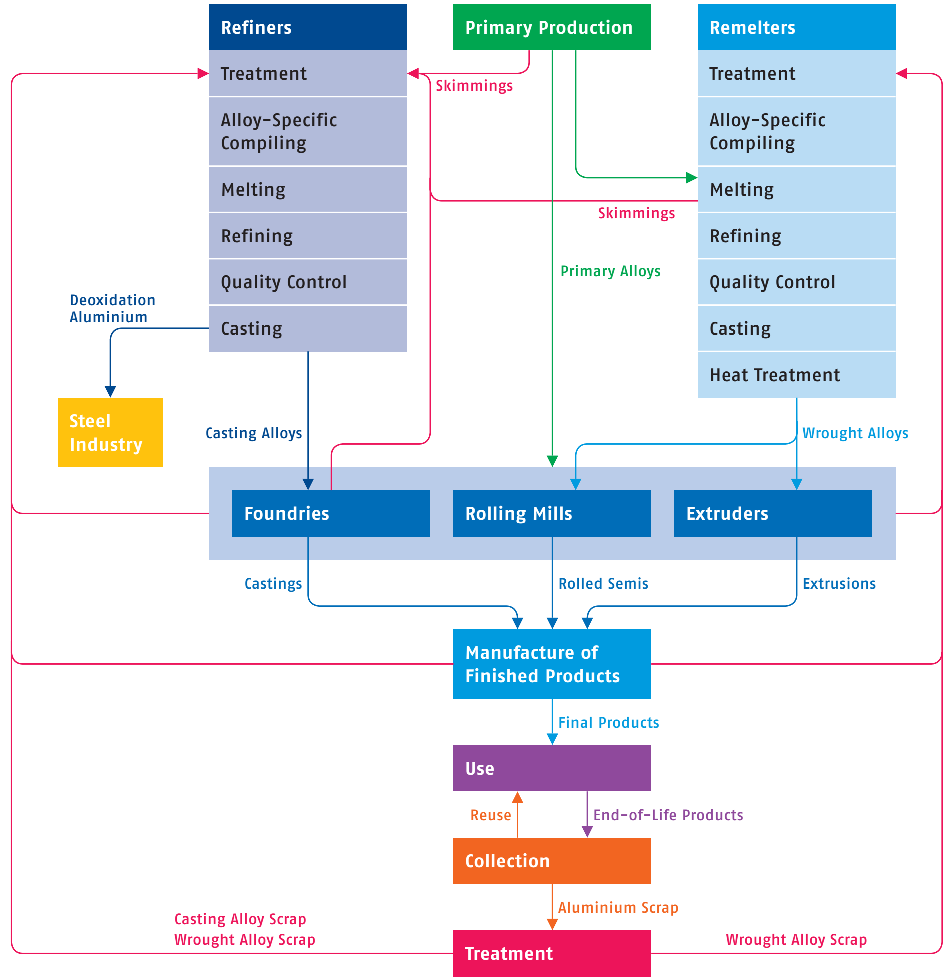
The Process of Recycling Aluminium

The preparation processes used to recycle scrap aluminium, both production and post-consumer scrap, is dependent on the use and related finishes or contaminants.[58]

The main preparation processes for the recycling of aluminium are as follows:

Source	Process
Foundry scrap	No processing required
Mill finish sheet off-cuts	No processing required
Turnings	Drying and de-oiling
Cans and rigid packaging (used)	De-lacquering and bailing
Flexible packaging (used)	Bailing
Thermally broken windows	Stripping out thermal brake (de-coating before recycling is not required)
Building components	Cutting and bailing

Table 2.5 The main preparation processes for the recycling of aluminium



* *Wrought alloys used by remelters have a different chemical composition from those used by refiners*

Fig. 2.33 Stages in the production of aluminium components, including recycling

Figure 2.34 illustrates the recycling process for scrap that is 100 per cent coil-coated aluminium sheets and the process for scrap that is coil-coated aluminium sheets combined with other materials. Beyond separation, in the second flow chart, the key difference is that 100 per cent coil-coated aluminium sheets can be closed recycled back to aluminium sheet, whereas the aluminium from a mixed-scrap source is typically refined and used to make aluminium castings.

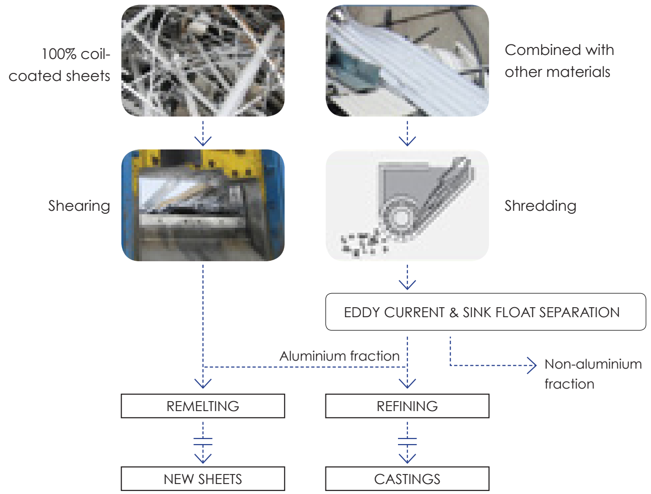


Fig 2.34 Comparing the recycling process for scrap that is 100% coil-coated aluminium sheets and for mixed scrap that includes coil-coated aluminium sheets

Fig 2.35 Shredded aluminium scrap

The process used to remove rolled-in polyamide thermal brakes from thermally broken aluminium window frames enables the aluminium to be recycled either as a closed loop to form new extruded aluminium window profiles or as cast aluminium.

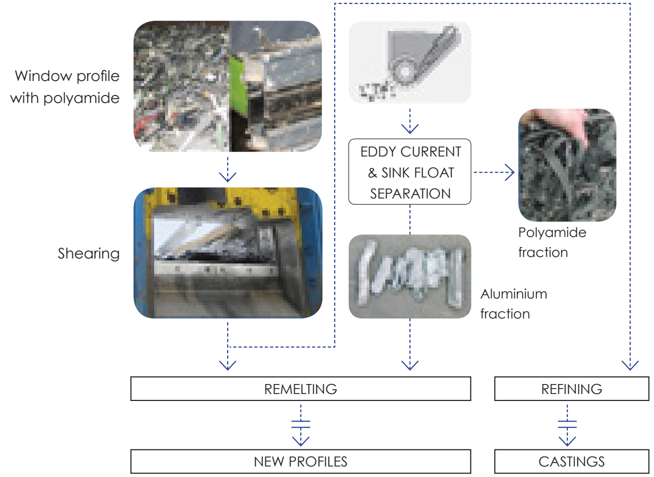


Fig 2.36 Recycling of coated and thermally broken aluminium window frames

Fig 2.37 Casting recycled aluminium

Conventional wisdom on recyclability advises against forming composite construction with dissimilar materials bonded together as it is relatively difficult to separate the layers of the composite back into layers of materials for recycling. The advantage of composite construction is that dissimilar materials with complementary properties can be bonded together to form an added-value product. For example, bonding aluminium onto a PVC or extruded polystyrene core combines durability, flatness and thermal separation, which is ideal for cladding. Three processes are available to enable the aluminium in composite panels to be recycled, as illustrated in Figure 2.38: delamination, knife milling and shredding.

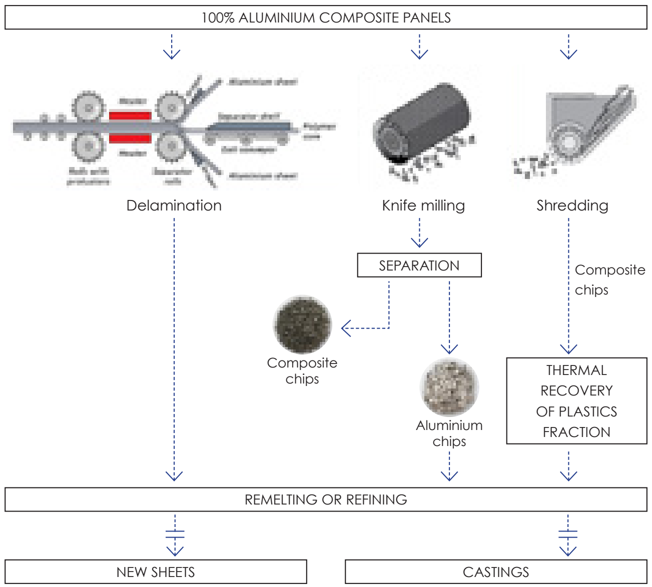


Fig 2.38 Recycling of aluminium composite panels

Fig 2.39 Extruding aluminium profiles

Fig. 2.40 Pouring molten recycled aluminium in a foundry

The Advantages of Recycling Aluminium

The advantages of recycling aluminium include:

- significant energy savings of up to 95 per cent compared to the production of primary aluminium;
- reduced waste disposal and landfill;
- reduced capital cost of only 10 per cent compared to primary smelting.[59]

Recycling aluminium requires up to 95 per cent less **primary energy**[60] than producing aluminium from bauxite.[61] Within Europe, the primary energy required to produce primary aluminium ingots is 157 MJ/kg; however, this figure is dependent on the efficiency of the energy mix used for smelting. In comparison, the primary energy required to produce recycled aluminium ingots is 7.85 MJ/kg. This is based on a 50/50 aluminium mix of process scrap and post-consumer scrap, such as recycled window frames.[62]

Embodied Energy in the Building and Construction Industry

Embodied energy is 'the initial energy investment required to produce a material or product'.[63] It includes the energy required for extraction of natural resources, manufacturing, transportation and construction, but critically it does not include use phase or end-of-life energy savings and therefore cannot be used for comparative purposes. Therefore, the total embodied energy of a building or building material is the total amount of energy necessary to produce and process all materials (from virgin or recycled sources) required to bring a product or full building into operation. In the 1970s and 1980s, there was a movement to calculate the embodied energy of buildings and building products as a way of quantifying the value of construction, renovation and reuse of building components and complete structures.[64] At the time, the argument made was that saving buildings from demolition, and therefore keeping that embodied energy locked up in existing building stock, could be equated with energy savings and support a broader sustainability agenda.

In economic terms, embodied energy locked up in existing building stock can be seen as a 'sunk cost', posing no inherent energy saving since that energy expenditure occurred in the past, as did the environmental impacts already incurred.[65] In this paradigm, the only real saving associated with retaining existing building stock, or building components, is the avoidance of environmental impacts associated with not constructing or manufacturing the new building or product.

Three variables in particular inform the embodied energy approach for evaluating aluminium in building components:

1. Aluminium has a very high recycling rate and it retains its value in terms of embodied energy through recovery, reprocessing and remanufacture, resulting in a large difference between the embodied energy of primary and recycled aluminium. For this reason, the allocation of impacts from raw material production must be equitably (and consistently) shared between products through careful end-of-life modelling, a practice that is well developed but constantly evolving.
2. Aluminium's exceptional durability challenges the direct comparison of products with different base materials, such as aluminium, steel, wood and plastic mullions, in terms of initial material inputs, as building products may have large differences in expected usable life and therefore different replacement cycles over the lifetime of a building.
3. Newly manufactured building components often display higher efficiency related to savings in operational energy – a crucial component of understanding the full impacts of building and construction. Typically, this is influenced by the other materials in an aluminium-based building assembly, such as the insulating core of an aluminium composite panel or a double- or triple-glazed unit within a high-performance aluminium curtain-walling system.

Together, these three factors make studies of embodied energy that rely on **cradle-to-gate LCA** of materials or typical assemblies less useful for aluminium than they may be for more basic building materials such as brick and concrete block. As many of the unique attributes of aluminium are evidenced over time, it is no surprise that assessments with limited scope are unable to fully characterise these attributes and may be less able to accurately compare products and assemblies across material types.

A more holistic building life cycle approach to embodied energy accounting places less emphasis on the product at the point of sale and allows for a comparison of materials and products based on their intended performance and their role in architectural assemblies and building systems. This approach allows designers and building owners to ask questions that are directly tied to design and management decisions, exploring relationships such as the comparison of the value

of retaining building components with the production of newer, potentially more efficient assemblies. It can also productively inform other aspects of the sustainability conversation, such as material durability, as shown in the chapter *Life Cycle Assessment of Window-Framing Materials* in *Aluminium and Life Cycle Thinking*, the third report of the Towards Sustainable Cities Research Programme.

Embodied Energy of Aluminium

Hammond and Jones provide a more complete definition of embodied energy in *Embodied Carbon: The Inventory of Carbon and Energy [ICE]*. This inventory includes both embodied energy and embodied carbon.

> Embodied energy [is] the total primary energy consumed … from direct and indirect processes associated with a product or service and within the boundaries of cradle-to-gate. This includes all activities from material extraction (quarrying/mining), manufacturing, transportation and right through to fabrication processes until the product is ready to leave the final factory gate.[66]

Caution needs to be exercised in the use of embodied energy figures, as often the published figures are based on historic data and therefore do not allow for improvements in production techniques and reductions in energy requirements, as noted above. Hammond and Jones also observe:

> There is a considerable temptation for inexperienced users of the ICE database to examine the embodied energy and carbon values as printed in the summary tables to instantly 'determine' the 'best' materials. This type of analysis must not be completed. The data within the ICE database is typically in the units MJ or $kgCO_2$ per kilogram of material, which is not a fair functional unit for material comparisons.[67]

They cite aluminium as a case for a more informed approach:

> An example of a set function is the examination of wall cladding systems. There are competing cladding systems and materials and each set will have different material quantity requirements. For example, aluminium has a lower density than steel and so aluminium cladding would typically require a smaller mass of material than if the cladding were made from steel.[68]

Using the end-of-life recycling method, ICE states that the embodied energy of extruded aluminium is 53 MJ/kg, with an embodied carbon figure of 3 kgCO_2e/kg.[69] ICE is specifically focused on the UK and the figures are based on a recycling rate of 90 per cent and a process loss of 2 per cent.[70] This recycling rate for aluminium is somewhat pessimistic given that the TU Delft study recorded rates of 92 to 98 per cent (see Table 2.4), with the recycling rate from the aluminium roof and other components of Wembley Stadium recorded as 96 per cent.[71]

The Importance of Embodied Energy in Low-Energy Architecture

With the successful delivery of low-energy architecture, the embodied energy of building materials and construction becomes increasingly important. 'The energy consumption attributed to a building material's life cycle may at present be comparatively far less than operations energy, with current figures indicating that building materials represent anywhere from 2 to 38 per cent of a building's lifetime energy consumption depending upon building type and location. However, this range has increased from 9 to 46 per cent for high performance buildings as a result of voluntary standards and stringent energy codes within building regulations.'[72]

Full life cycle impact assessment is likely to grow in importance and popularity in the near future as low-carbon energy-efficient buildings become the norm and programmes such as the Architecture 2030 Challenge for Products, BREEAM and LEED continue to advocate life cycle modelling for architecture products. This is a component of a design approach that seeks to decrease the carbon footprint of projects, progressing towards carbon-neutral buildings.

From Embodied Energy to Environmental Impacts

In the last decade, as the methods and means of environmental assessment have evolved, there has been a move away from a reliance on proxy measures of sustainability, such as embodied energy, and towards direct measures of environmental impacts (including global warming, acidification, eutrophication, photochemical smog formation, ozone depletion, human health/toxicity and land use degradation). Not only have concerns broadened beyond that of energy consumption, but the resolution and availability of data on the flows of materials and chemicals within the environment have improved, as has the ability to describe relationships of causality and impact.[73] While embodied energy can be used to understand aspects of manufacturing efficiency and help to evaluate inherent differences between materials and their modes of production, reliance on embodied energy as the sole sustainability metric for the evaluation of materials, architectural products and whole buildings is potentially limiting. New calculation methodologies and databases, such as multi-impact life cycle assessments, have increased in resolution and offer a more complete understanding of the environmental impact of construction across a range of impact categories. It is also pertinent to observe that the aluminium industry was an early adopter of the use of LCA, as recorded by Elizabeth Trenton.[74]

To illustrate the limitations of focusing on embodied energy, consider the following example. A construction material whose manufacturing relies upon hydroelectric power is not necessarily as impactful as another product whose manufacturing relies upon the same amount of electricity or heat produced by a coal plant, although both products' embodied energy would be expressed identically. Hydroelectric power is a renewable energy resource, whereas fossil fuels are a non-renewable resource whose extraction and combustion have clear and definable environmental impacts. Conducting environmental assessments from a potential impact

Fig. 2.41 The Loblolly House, designed by KieranTimberlake, is an example of reversible construction, which uses Bosch Rexroth aluminium extrusions

perspective helps to clarify and reveal variations between **energy mix** and manufacturing processes across space and time. In terms of environmental impacts, not all megajoules are equal.[75] Indeed, the aluminium industry has long accounted for regional energy blends in its own life cycle inventories and impact assessments.[76] At a time marked by concerns over climate change and human health, these concerns are far better tracked through measures of impact, not just inventories.

Fully Reversible Construction: Future Best Practice

One of the recommendations based on the research in *Aluminium and Durability* is that design and construction details for aluminium building components should be reversible, either to facilitate refinishing, relocation or recycling, for the long term. When the aluminium finish eventually needs recoating, or the building needs to be relocated, or the building is no longer required, then the components can be recycled.[77] Design for Disassembly [DfD], also known as Design for Deconstruction, is widely advocated as a means of minimising or avoiding waste from construction, as stated in the ICE Demolition Protocol. A useful design guide on DfD has been prepared by Chris Morgan and Fionn Stevenson for the Scottish Ecological Design Association. They state that:

> Designing details for deconstruction at the start of a project enables one building, at the end of its useful lifespan, to be the resource for the next and helps 'close the loop' for resource use. It also designs out future risk and cost by ensuring that building elements and products can be quickly and easily maintained and replaced.[78]

Brad Guy and Nicholas Ciarimboli, whose own guide owes an acknowledged debt to that of Morgan and Stevenson, define DfD as

> the design of buildings to facilitate future change and the eventual dismantlement in part or whole for recovery of systems, components, and materials. This design process includes developing the assemblies, components, materials, construction techniques, and information and management systems to accomplish this goal. The recovery of materials is intended to maximise economic value and minimise environmental impacts through subsequent reuse, repair, remanufacture, and recycling. Of last resort are energy recovery from materials and safe biodegradation. DfD enables flexibility, convertibility, addition, and subtraction of whole buildings.[79]

Fig. 2.42 Cellophane House™, designed by KieranTimberlake, being assembled and disassembled in prefabricated chunks at MoMA, New York, 2008

Consideration of how readily architecture could be disassembled was pioneered by the English architect Cedric Price in the 1960s. Designs for assembly and disassembly were developed and articulated by product designers, especially automotive designers, in the 1990s.[80] The concept of DfD had become well established in the realm of mass production by the early 2000s.[81] DfD is a principle applied during the design process that results in the detailing of reversible joints, connections and attachment mechanisms between building materials and building components, as defined above. The application of DfD principles facilitates the dismantling of the whole building or selected components in the future, thereby ensuring that materials and/or components can be recovered, sorted, reused or recycled. Guidelines were adapted for buildings in the mid-2000s.

There is also a call for the increased consideration of DfD with respect to curtain walling, especially in the context of tall buildings and even ultra-tall buildings, as the life expectancy of these buildings is likely to be longer than the service life of the building envelopes initially used to clad them. Patterson and colleagues have proposed that this, combined with durability, should become a fundamental consideration for all new curtain-walling systems.[82] In the mid-1980s, the author invented the Aspect 2 cladding system, a fully integrated system of panels, windows and doors which offered total interchangeability to all concerned in the process of design and construction, and which also extended this advantage to the use phase – to the building owners and users. Essentially, the advantages offered by this approach were available to all parties, including the end-of-life scenario of disassembly. Aspect 2 offered on a product basis the advantages demonstrated by Foster Associates at the Sainsbury Centre at the University of East Anglia, completed in 1978, and the Herman Miller building in Chippenham, completed in 1983; both projects feature in the first report in the Towards Sustainable Cities Research Programme, *Aluminium and Durability*.[83] In essence, best practice preceded research in the case of DfD of architecture. Aspect 2 was used to clad a wide range of projects, from offices in the City of London to the St James' Park football stadium in Newcastle.

In part, the move towards DfD was driven by regulations – for example, the EU Waste Electrical and Electronic Equipment Directive [WEEE] 2002, which became part of EU law in 2003. At about the same time, DfD entered the literature of architecture and construction.[84] It is reasonable to predict that the use of

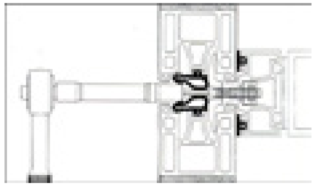


Fig. 2.43 Aspect 2 cladding system detail, designed by Michael Stacey

Fig. 2.44 Panel locking system, designed for disassembly

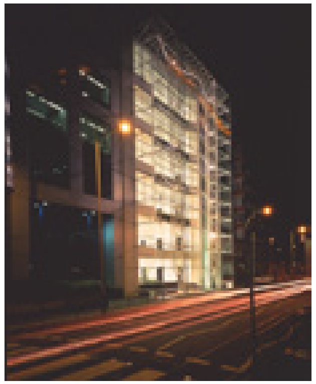


Fig. 2.45 Implementation of Aspect 2 cladding at Lotts Row, City of London by project architect John Winter

1. Factory-fitted primary tubular EPDM gasket with moulded tubular corners
2. Dual-hardness EPDM horizontal air seal
3. EPDM vertical air seal
4. PVCu edge section (grey) Welvic R67-915
5. PVDF aluminium panel skin
6. Standard core – extruded polystyrene
7. Extruded aluminium clamping plate. Stainless steel Allen head machine screw fixed to an extruded rear block with captive stainless steel Nylock
8. Extruded aluminium rear carrier

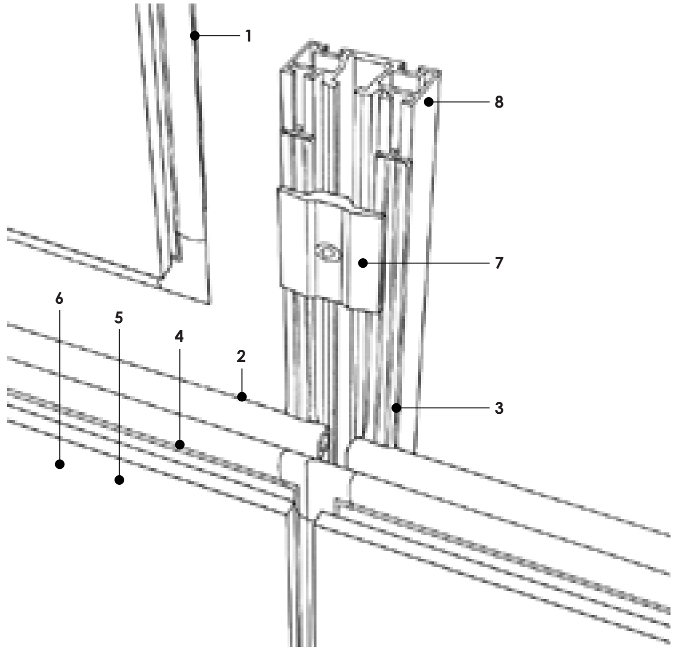


Fig. 2.46 Panel assembly drawing of Aspect 2, designed by Michael Stacey

Fig. 2.47 Aspect 2 cladding system installation

Building Information Modelling [BIM] for design and facilities management will also facilitate the reuse, relocation and recycling of architectural components, as information on all materials – including the specific alloys of aluminium components – and their incorporation in the building will be retained.

Cellophane House™ (2008), designed by KieranTimberlake using BIM software, is a pioneering example of this approach.[85] Following the exhibition of this prefabricated home at MoMA in Manhattan, all of the house's components were recovered, achieving a collection rate of the aluminium frame of 99.99 per cent; only a small quantity of concrete was left in the ground. The high-tensile steel bolts connecting the extruded aluminium frame could not be reused, but they could be recycled. This case study is set out in detail in Chapter Four.

The graph in Figure 2.48 shows a comparison of operational and embodied energy in Cellophane House™, highlighting that if a high degree of reuse and recycling is achieved, future architecture can not only be carbon neutral, it can even be a net contributor to the future energy balance.

The reuse of valuable building components is actually a long-standing practice. St Albans Cathedral, in England, was constructed from reclaimed Roman bricks in an era when brick making was a lost art. In Byzantium/Constantinople/Istanbul, the wonderfully engineered underground water reservoirs reuse Greek and Roman masonry building components, typically temple columns. Some describe this as architectural bricolage. Therefore, the twenty-first century will see a renaissance of reuse but with a wider range of materials, including aluminium. This may apply more often to structural aluminium components, as seen in Jean Prouvé's Aluminium Centenary Pavilion, discussed in Chapter Four, rather than aluminium components that are difficult or impossible to remove during disassembly, such as aluminium carpet trims, which are more appropriately recycled than reused. Therefore, in future a component-specific approach is required.

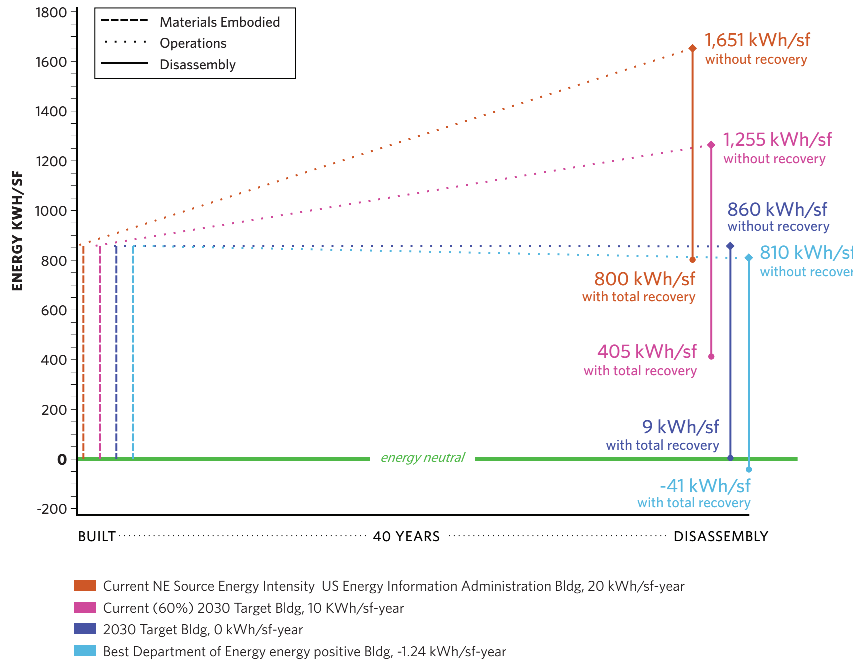


Fig. 2.48 KieranTimberlake's comparison of operational and embodied energy of Cellophane House™, highlighting the importance of recovering the embodied energy

An Age of Resourcefulness

In the second decade of the twenty-first century, humankind is entering an age of resourcefulness. The excesses of the consumer society that was initiated by the explosive growth of North America after the Second World War are coming to an end. Bill Bryson has observed that 'by 1955 the typical American teenager had as much disposable income as the average family of four had enjoyed fifteen years earlier'.[86] As energy becomes more expensive, it is essential for humankind to deliver services and products with less material, combined with reuse and recycling. During the in-use phase, the careful stewardship of architecture and infrastructure is also essential, although progress to resourcefulness is not a simple or linear process as it can be characterised by a paradigm clash between market preconceptions and more responsible modes of procurement, combined with intelligent design, informed material selection and appropriate manufacturing practices. Such resourcefulness is demonstrated in KieranTimberlake's Cellophane House™ and is at the core of initiatives such as the ICE Demolition Protocol.

Aluminium and Durability documents how exemplars of the use of aluminium within architecture will last over 120 years.[87] Aluminium in architecture and infrastructure represents a reservoir or energy bank for humankind.

Remanufacturing

Producers of high-value mechanical equipment such as construction and mining equipment have demonstrated resourcefulness by implementing **remanufacturing** – returning a product to its original performance specification. This provides an end-of-life to same-as-new service, which creates a closed loop that minimises material recycling. Both Caterpillar and JC Bamford Excavators [JCB] take back parts, machinery and equipment, disassemble them to the smallest components and remanufacture the components where necessary to original standards. The remanufactured parts are protected by the same warranty as offered on new parts. JCB advise 'typical savings against new of 40–50 per cent, and the remanufactured parts can restore machines to their optimum condition at a more affordable price. Furthermore, remanufactured parts are upgraded to incorporate the latest technology.'[88] In 2012, Caterpillar 'took back over 2.2 million end-of-life units for remanufacturing'.[89] Will the near future see major manufacturers of curtain-walling systems taking back aluminium components and upgrading them by remanufacturing? Or will the long life expectancy of curtain-walling systems preclude this?

Fig. 2.49 Thames Water Tower, London, architect Brookes Stacey Randall Fursdon

Potential Use of Aluminium to Improve Building Performance and Reduce Demolition

Buildings account for around 45 per cent of all carbon emissions in the UK; in the USA, the figure is just over 40 per cent.[90] Thus there is a significant focus on the design and construction of new buildings with low carbon footprints. However, the energy performance of existing buildings also needs to be improved. It is not viable to demolish and replace them all, a move that would have its own implications for carbon emissions, as clearly observed in the Preservation Green Lab report.[91] Instead, an existing building can be adapted and, most importantly, the building envelope can be thermally improved. There are three methods to achieve this:

1. reglazing/refenestration;
2. over-cladding the existing façade;
3. stripping back and replacing the existing façade, potentially incorporating a new plan form.

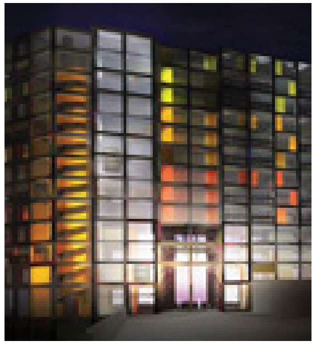


Fig. 2.50 Park Hill at night, incorporating anodised aluminium panels as part of redevelopment by architect Hawkins Brown and Studio Egret West

Technical Updating of the Building Envelope

There is potential for using aluminium to replace thermally obsolete and/or corroded windows in existing buildings. These examples range from replacement windows to the replacement of an entire curtain-walling façade.

Build date	Project	Previous type of window/ curtain walling	Current type of window	Age	Replacement date	Age of window replaced
1902	Flatiron Building, New York, Daniel Burnham	Wood clad in painted copper	Traco TR-9000 H-AW45 Double-Hung Tilt Aluminum Architectural windows	113 yrs	2006	104 yrs
1931	Empire State Building, New York, William F. Lamb	Painted steel	Traco TR-9000 H-AW45 Double-Hung Tilt Aluminum Architectural windows	84 yrs	1993	62 yrs
1952	Lever House, New York, SOM	Stainless-steel-based curtain walling	Aluminium curtain walling	63 yrs	2001	49 yrs
1952	UN Secretariat Building, New York, Harrison & Abramovitz	Aluminium curtain walling	Aluminium curtain walling	63 yrs	2007	55 yrs
1974	British Arts Center, Yale, Louis I. Kahn	Steel curtain-walling system	Aluminium curtain walling	41 yrs	2006	32yrs

Table 2.6 Age of window and curtain walling upon replacement on key North American projects.

Fig. 2.51 The Churchill Centre designed by Brookes Stacey Randall Furdson, uses a combination of glazing and an extruded terrecotta rainscreen to reinvent a largely vacant 1970s shopping complex

The average age of these North American projects upon reglazing is over 60 years. The motivation for reglazing, beyond the replacement of corroded steel sections, is the creation of façades with much lower U-values using contemporary high-performance double- or even triple-glazed units. This can be combined by careful specification of the window or curtain-walling system with a much lower air infiltration rate, also key for increasing comfort while using less operational energy. Another factor can be the need to upgrade the façade to withstand acts of terrorism, as was part the reason for updating the curtain walling of the UN Secretariat Building in New York.

Facaderetrofit.org, a web-based resource for building façade retrofit that includes a database of international façade retrofit projects, referred to earlier in this chapter, has a research scope to study this topic in greater depth. At the time of writing, the database is in beta testing. Our analysis of this research reveals that the average age of buildings at the time of curtain-walling retrofit is almost 40 years, with projects in Peru, Norway, North America and the UK. For reinvention and over-cladding, the average age of the buildings is over 70 years, with projects mainly in North America although with some examples from Norway and Germany. Interestingly, this research establishes an average age of buildings for window replacement of over 70 years.

Reglazing/Refenestration Case Studies: Aluminium Preserving Modern Landmarks

Some of the first curtain walls to be installed do not meet contemporary thermal needs, as well as having structural/material issues. In the case of the UN Secretariat Building, the original curtain walling did not meet the need to be blast-proof after 9/11 and the destruction of the World Trade Center towers in New York.

The UN Secretariat Building and Lever House were both completed in 1952, enclosed with curtain-walling systems. Around 50 years later, in 2001 and 2007 respectively, both of these were replaced with better-performing aluminium systems.

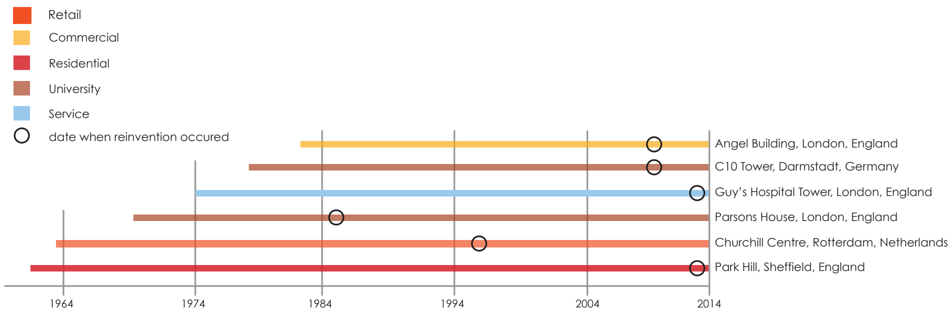


Fig. 2.52 Graph of reinvention and overcladding case studies

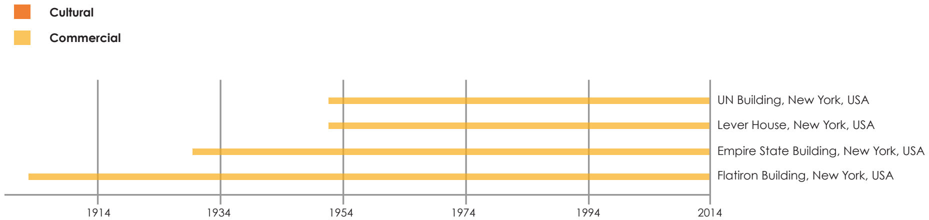


Fig. 2.53 Graph of window replacement case studies

The UN Secretariat Building, New York: Architect Harrison & Abramovitz, Completed 1952 and Updated 2007

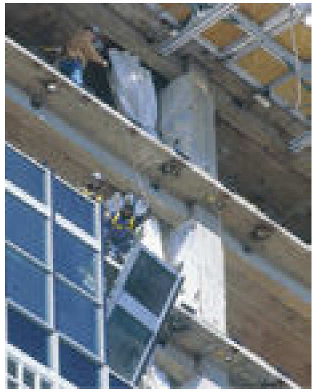
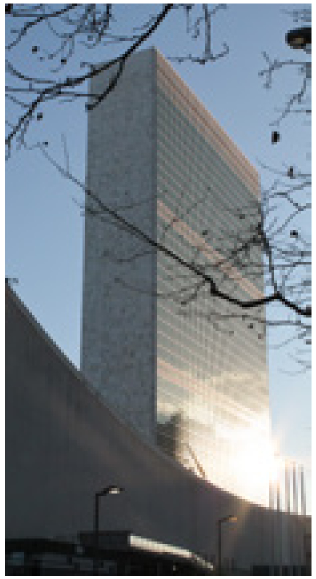


Fig 2.54 Replacement of the panelised curtain-walling system of the UN Secretariat Building in 2007

Fig 2.55 [below] The 39-storey UN Secretariat Building, executive architect Harrison & Abramovitz, photographed in 2013. The replacement aluminium curtain walling maintains the original appearance.

Fig 2.56 [below right] Replacement aluminium curtain walling of the UN Secretariat Building, photographed 2013

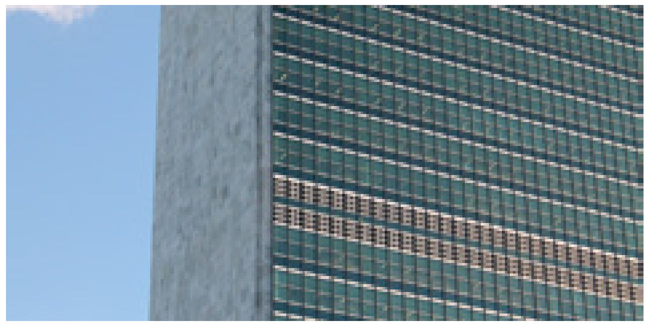


The 39-storey UN Secretariat Building was designed in the 1940s by Harrison & Abramovitz and construction was completed in 1952.[92] The original design incorporated one of the first aluminium curtain-walling systems, which was replaced in 2007. The new design was required to be blast-proof (post-9/11) and to bring the building up to contemporary energy standards, whilst respecting the original design. Architecture firm HLW International led the renovation, with consultancy from R. A. Heintges Associates.

The replacement curtain walling is a panelised system, which matches the dimensions of the original curtain wall almost exactly – each panel being two 1200 x 1180mm glass modules to imitate the original operable windows. Although the new windows are not operable, as this would negate the blast protection, an intermediate horizontal mullion creates the look of the original double-hung window. During the design stages of the replacement curtain-walling system, many prototypes were taken to site to compare finishes, depth and reflectivity of the glazing.

Harrison & Abramovitz originally specified a No.4 finish for the aluminium mullions, to imitate the finish of stainless steel, used at a similar time for the Lever Building. Matching this proved challenging for the replacement mullions; Heintges, the façade consultancy company, advised that a No.4 finish is 'not a good finish for aluminium, as all the scratches get filled with atmospheric contaminates and it starts to get dirty and pitted'.[93] Instead, the extrusions were given a gentler brushed finish and a protective coating using fluoropolymer coating [PVDF].

Demolition of the old curtain wall and installation of the new went from the bottom up in three sections, starting with the top third of the building, then the middle third, and finally the storefront and bottom third. The new curtain wall followed behind the old by approximately three floors.[94]



Lever House, New York: Architect Skidmore, Owings & Merrill, Completed 1952 and Updated 2001

This new office for the British soap manufacturers Lever Brothers, designed by Skidmore, Owings & Merrill [SOM], was built on Park Avenue, Manhattan, between 1951 and 1952. Gordon Bunshaft was the lead architect and partner in charge of this project for SOM. It was one of the first sealed-glass buildings to be constructed. The original curtain wall deteriorated, mainly from water damage resulting in bowing of horizontal mullions, breakage of spandrel glass panels and cracking of wired spandrel glass due to thermal stress. In order to preserve the modern landmark without changing its appearance, the original curtain walling was replaced with a double-glazed aluminium curtain-walling system under the direction of SOM in 2001. The system used aluminium glazing channels, stainless-steel mullions and caps and new panes of heat-strengthened glass produced by PPG.

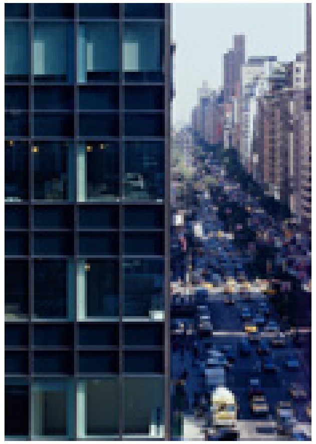


Fig 2.57 The new curtain walling of Lever House, photographed 2013

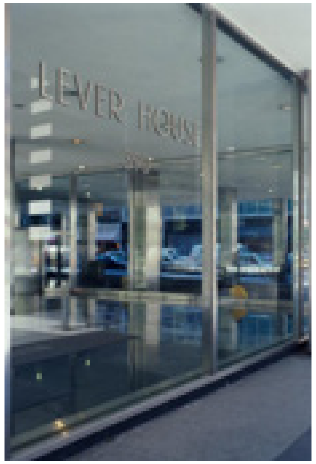


Fig 2.58 Entrance to Lever House, photographed 2013

Fig 2.59 [left] Lever House designed by Skidmore, Owings & Merrill, after re-glazing using aluminium, photographed 2013

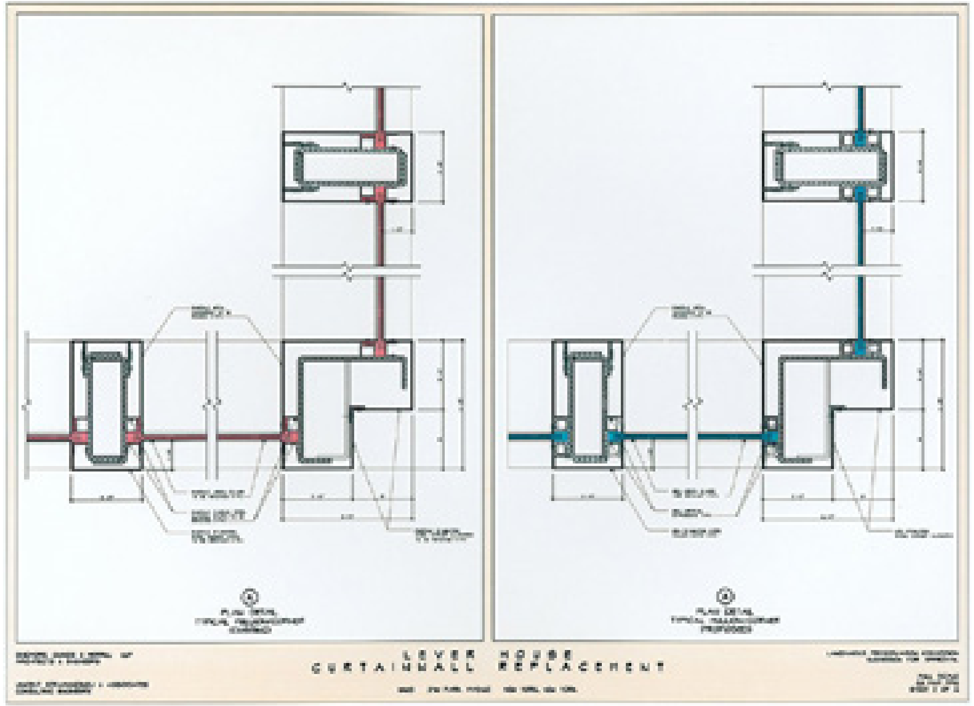


Fig 2.60 [top right] Original and replacement corner curtain-walling details for Lever House

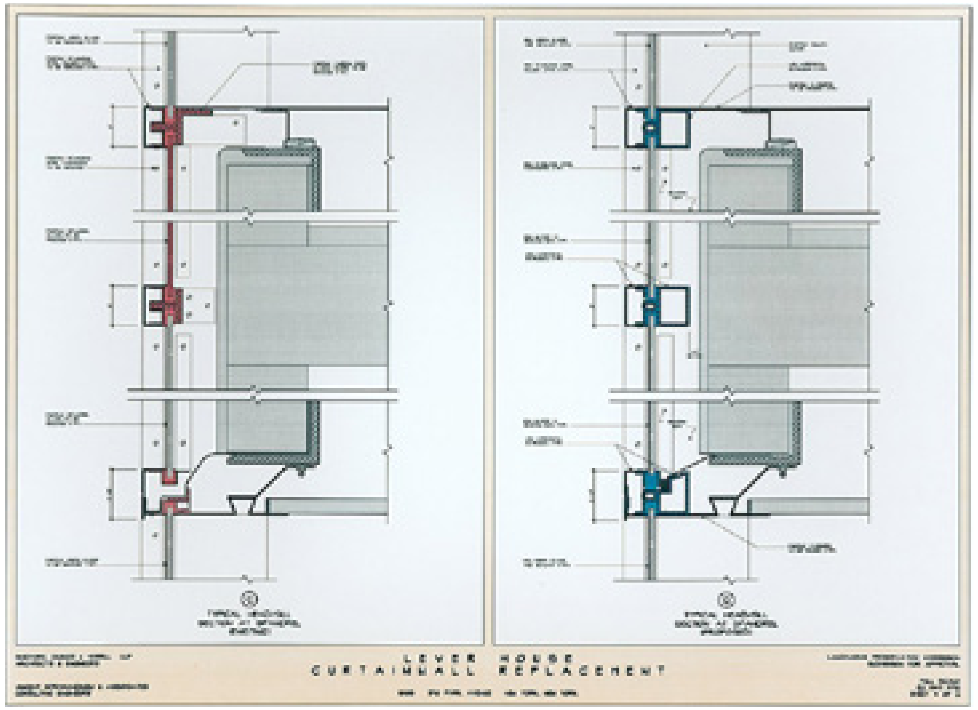


Fig 2.61 [right] Original and replacement curtain-walling details for Lever House

Aluminium Windows and the Heritage Market

Aluminium has become an important material within the heritage market. The continuing need to bring ageing buildings in line with current energy use standards has seen a number of window manufacturers targeting this market with aluminium products.

An aluminium extruded window makes a good replacement for an existing building to improve the thermal performance, provide durability and reduce the amount of maintenance required. Aluminium windows can be powder coated or anodised, and it is possible to match the colour of existing windows for heritage properties. Aluminium windows are often slimline, making them a reasonable replacement for Crittall steel or cast-iron windows.

Two examples where aluminium glazing has been used to replace corroding metal windows in heritage buildings are the Flatiron Building and the Empire State Building, both in New York.

Fig 2.62 Slimline powder-coated aluminium windows, designed to replace thermally obsolete metal windows in existing buildings

Fig 2.63 Empire State Building, architect William F. Lamb of Shreve, Lamb & Harmon Associates, viewed from Fifth Avenue

The Empire State Building, New York: Architect William F. Lamb of Shreve, Lamb & Harmon Associates, Completed 1931 and Updated 1993

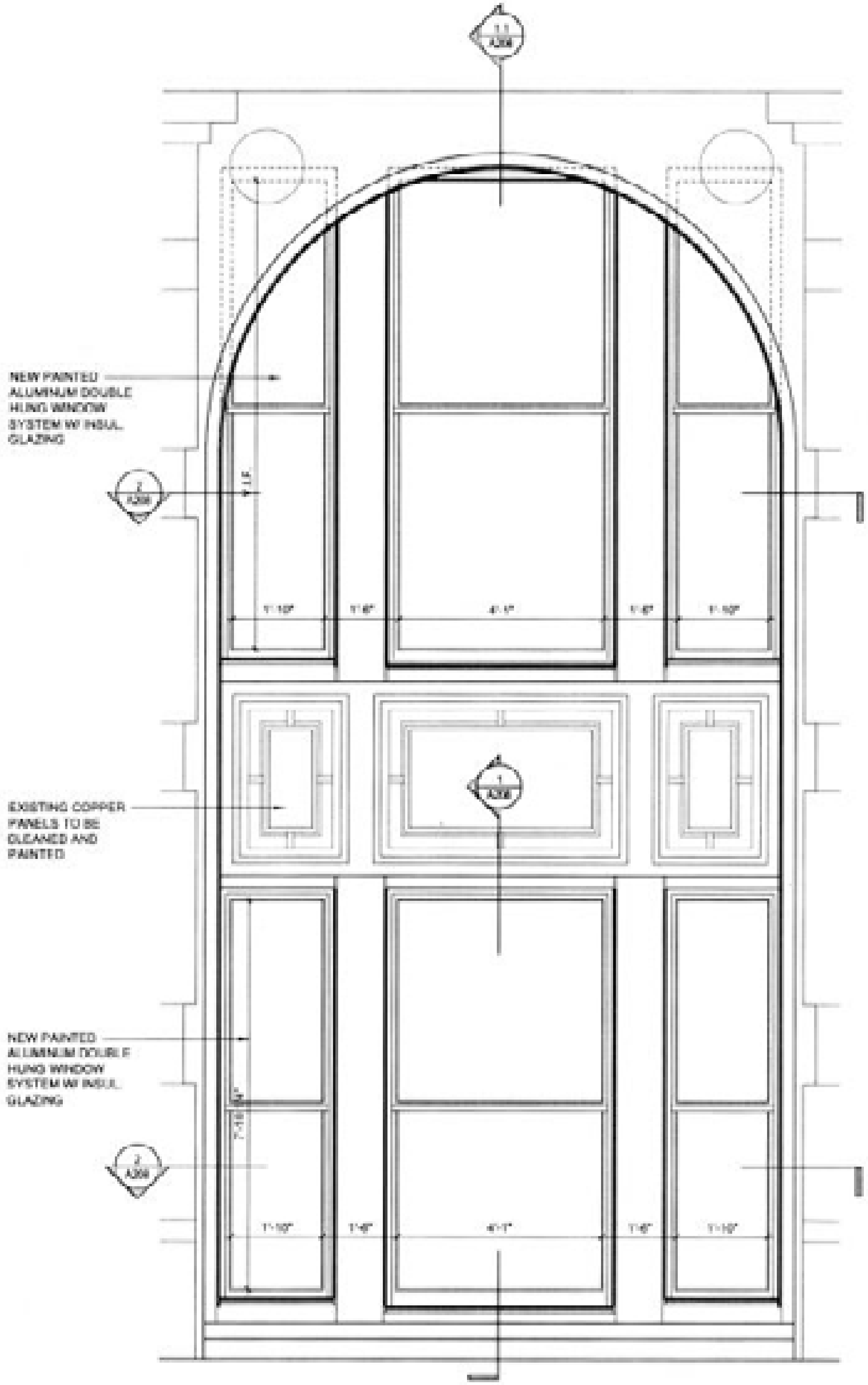
Fig 2.64 Corroded steel frame of the Empire State Building during renovation

Completed in 1931, the Empire State Building uses steel-framed construction, clad in brick and limestone alternating with vertical ribbons of steel windows with aluminium spandrel panels below. It stood as the tallest building in the world until the World Trade Center towers were built in 1972. In 1993, after 62 years of service, the 6,400 steel windows were corroded and required refurbishment. Two options were evaluated:

1. Each window could be removed and the existing 12 coats of paint stripped back. The corroded steel would then be prepared and treated with two or three new coats;
2. Each window could be completely removed and replaced.

The second option was taken, and the windows were replaced with aluminium double-hung tilt windows, as the restoration of the existing steel windows was not feasible due to the inevitable continued corrosion. The replacement windows were specified as series 9000 windows manufactured by Traco. The original window paint coatings were tested to determine the original colour, which was matched on the replacement windows.[95] The aluminium windows amount to 19,510m^2 (210,000ft^2) or 30 per cent of the exterior façade, and the replacement of these windows has equated to a 16 per cent annual energy saving.[96]

Fig 2.65 Ground-floor glazing detail of the Empire State Building



The Flatiron Building, New York: Architect Daniel Burnham, Completed 1902 and Updated 2006

Fig 2.66 Flatiron Building, architect Daniel Burnham, 1902

The Flatiron Building, originally the Fuller Building, was designed by Daniel H. Burnham & Co. and completed in 1902. It is one of New York's most identifiable landmarks, officially recognised as such in 1966 by the Landmarks Preservation Commission. In 2006, Fifield Piaker Elman Architects [FPEA] designed the building's window replacement programme, which required submission to and approval by this commission. Pre-design investigation revealed that the original windows were copper clad with a patinated finish. These single-glazed windows were double-hung wooden sashes. FPEA's approved design specified new double-hung windows, double-glazing and thermally broken aluminium frames with a custom-painted finish to match the original colour of the patinated copper. The windows were fabricated by Kawneer.

Fig 2.67 [left] Replacement aluminium window detailed elevation

Fig 2.68 Flatiron Building following the installation of new aluminium-framed double-glazed windows

Over-Cladding Case Studies: Aluminium Saving Money and Resources

Over-cladding is predominantly used for 1960s, 1970s and 1980s concrete-framed buildings, which are often structurally sound but thermally and aesthetically redundant. These buildings are mostly inefficient due to their leaky façades and lack of solar shading, causing them to lose heat in the winter and overheat during the summer. It can be disruptive and expensive to remove the existing cladding of an occupied building, particularly where the original insulation contains asbestos. Over-cladding allows the old façade to be left in place whilst a new envelope is constructed over the top. After construction, it is then possible to remove any unwanted components internally from the existing façade, such as windows or panels. This process allows the building's life to be extended, with lower energy demands and maintenance costs, at a fraction of the cost of erecting a new structure.

The following case studies demonstrate methods of aluminium over-cladding.

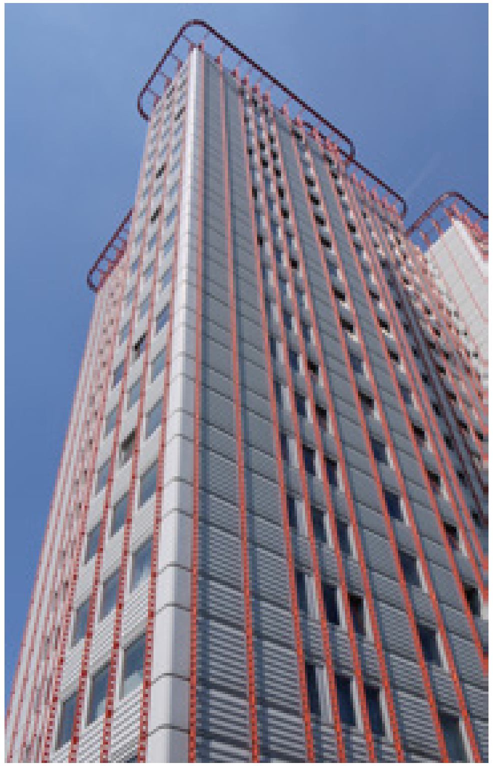


Fig 2.69 Parsons House over-cladding, designed by Peter Bell & Partners

Parsons House, London: Architect Peter Bell & Partners, Completed 1986

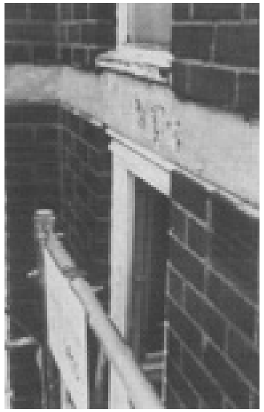


Fig 2.70 Parsons House before renovation

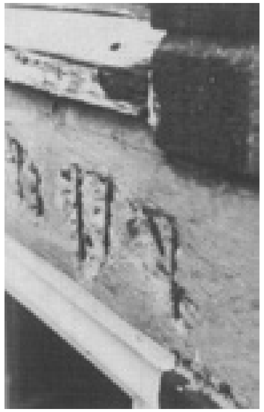


Fig 2.71 Parsons House before renovation – note the spalling concrete and rotten timber windows

The 21-storey tower at Hall Place in London, 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 during the 1960s was often poor; in part, this was 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 by the mid-1980s; as well as spalling concrete, there was 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 the 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 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 inherent in the original construction. On Parsons House, 80mm of mineral wool 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 noted that 'the cladding should not require repainting for 40 years'.[97] It is pertinent to note that the guarantees provided on polyester powder coating at the time were between 10 and 15 years only.

The C10 Tower, Darmstadt School of Applied Sciences, Darmstadt: Architect Staab Architekten, Completed 2010

Built in 1963, this tower was over-clad in 2010 by Berlin-based firm Staab Architekten. The 60m high building was stripped back to its original structure during the refurbishment. The windows were replaced and the outer walls fitted with Wicona curtain walling. The majority of the north elevation was glazed, and the south façade was fitted with striking solar shading to prevent the interior from overheating. The overlapping 3D aluminium façade elements are fixed. The building was awarded the 2013 German Façade Prize for curtain walling.

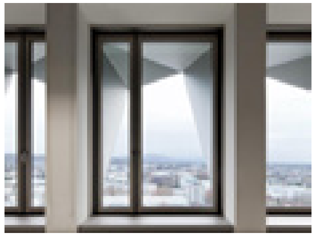


Fig 2.72 Inside the C10 tower, the folded aluminium façade components provide solar shading

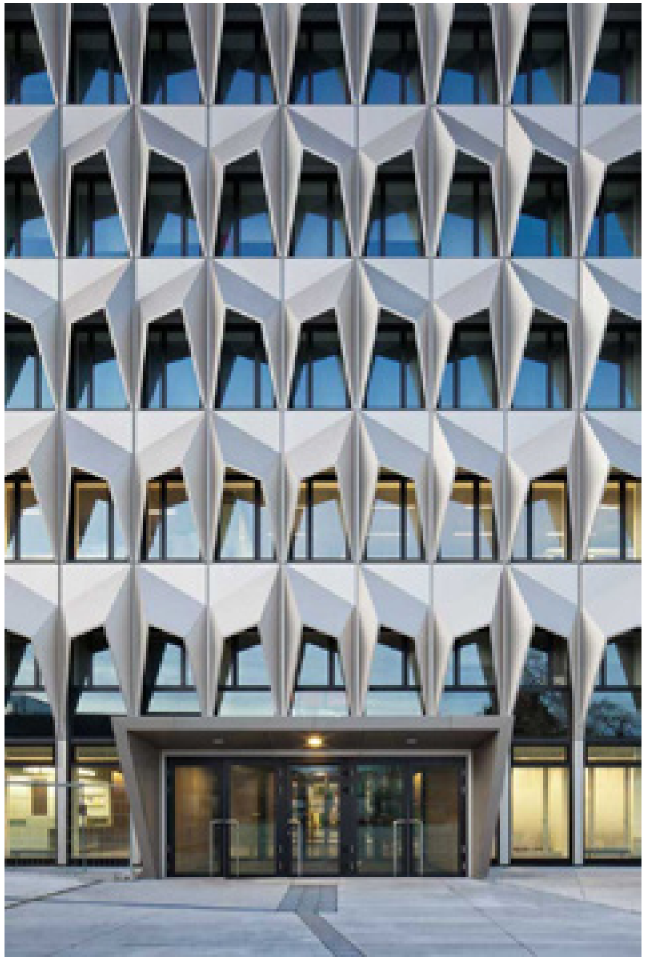


Fig 2.73 The C10 Tower with a new skin of aluminium curtain walling

Fig 2.74 Aluminium solar shading on the south façade of the C10 Tower, designed by Staab Architekten

Guy's Hospital Tower, London: Architect Penoyre & Prasad Architects, Completed 2013

Fig 2.75 Architect's render of proposed over-cladding for Guy's Hospital Tower, designed by Penoyre & Prasad Architects

Guy's Tower was designed in the early 1970s by Watkins Gray, opening in 1974. Now sitting beside the Shard, it was once the tallest building in London. Penoyre & Prasad Architects have designed a scheme to reclad most of the 34-storey tower.

The immediate problem was concrete spalling – concrete that is flaking, pitted or broken, usually due to corrosion of steel reinforcement bars. This exposed the steel reinforcing and the concrete to further corrosion, posing a risk to passers-by below. The concrete was stripped back and the reinforcement steel was treated and repaired.

An over-cladding system of anodised aluminium cladding and aluminium-framed double glazing provides an entirely independent thermal skin and enabled all work to be carried out externally, with the hospital maintaining fully functioning order. Once the over-cladding was complete, the existing windows were removed from inside. Arup, the project engineer, has estimated that the annual savings in operational carbon emissions through the more efficient cladding will pay back the embodied carbon spent in carrying out the refurbishment in about 13 years. Dan Cossins of Arup describes the cladding as 'the lowest possible embodied carbon solution'.[98]

Fig 2.76 Over-cladding of Guy's Hospital Tower designed by Penoyre & Prasad Architects with Arup, fabrication and installation by Permasteelisa

Reinvention or Deep Retrofit Case Studies: Aluminium Saving Energy and Resources

Some existing buildings require larger aesthetic transformations in order to be successfully reintegrated into the built environment. This method is predominantly used for 1960s, 1970s and 1980s concrete-framed buildings, which have large amounts of embodied energy in their structure and yet are architecturally obsolete.

Deep retrofit, or deep energy retrofit, is defined in North America as the retrofit of an existing building or buildings that involves at least a 30 per cent reduction in operational energy consumption. Unlike reinvention of an existing building, deep retrofit does not necessarily include the holistic re-evaluation of the architectural proposition. The following case studies demonstrate a strip-back–and-reinvent approach, all using aluminium in the new building fabric.

Fig 2.77 Churchill Centre, designed by Brookes Stacey Randall

The Churchill Centre, Rotterdam: Architect Brookes Stacey Randall Fursdon, Completed 1996

Completed in March 1996, this project involved a major reconstruction of a dilapidated 1970s shopping centre in Rotterdam, located above the city's busiest metro interchange. After options for the building were prepared and costed, it was decided that the largely vacant shopping centre should be stripped back to its concrete frame and reclad, providing a simpler and more sympathetic form whilst maximising the retail potential. A 40 per cent increase in lettable area was achieved. The new shop units were provided with uninterrupted glazed façades to the pedestrianised spaces, with terracotta rainscreen walls facing the road. Retaining the concrete frame had a range of advantages, which included the logistics of minimising the build over the metro station, saving in cost and embodied energy. The project was constructed using a design-and-build contract based on the practice scheme design drawings and specification showing the robustness of the detailing.

The Churchill Centre is a very successful project for developers Maasstede Vastgoed, as it is popular with tenants and shoppers and has added to the public realm of Rotterdam. All stakeholders can be served well by carefully considered architecture.

Fig 2.78 Before – 1970s shopping complex

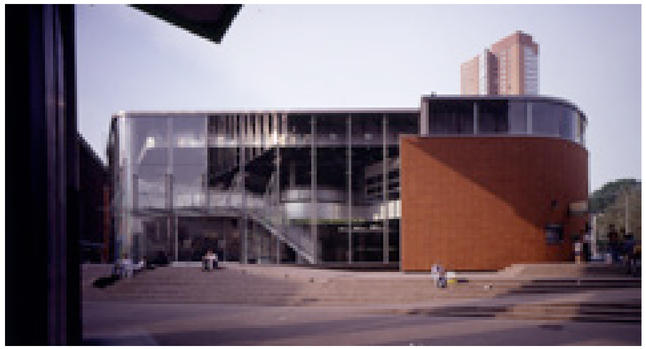


Fig 2.79 After – Churchill Centre in 1996

The Angel Building, London: Architect Allford Hall Monaghan Morris, Completed 2011

The Angel Building demonstrates the possibilities of reusing an unwanted office building without having to resort to demolition and new construction. The former Angel Centre was completed in 1981 and leased to a telecommunications company until 2006. The building then lay empty due to its outdated mechanical systems, inefficient layout and lack of aesthetic appeal, both internally and externally. Architects Allford Hall Monaghan Morris [AHMM], in collaboration with Derwent London, undertook a complete redesign of the site and reinvented it as a productive working environment.

The design process began with an architectural tour of New York and Chicago, where a number of the buildings provided inspiration, including the Manufacturers Hanover Trust building in New York, designed by Gordon Bunshaft of Skidmore, Owings & Merrill, and the Seagram Building, also in New York, designed by Mies Van der Rohe.[99]

Initial analysis of the existing building showed that while the façade and services were inadequate for further use, the in situ concrete frame had potential for reuse with a viable storey height of 3.7m. Avoiding the demolition and disposal of the existing concrete frame prevented the disposal of 39,500m^3 of concrete.[100] If the demolished concrete structure had then been replaced with a steel frame, this would have used 7,400 tonnes of CO_2 – roughly equivalent to the emissions of running the building for 13 years. Reuse of the frame had considerable cost savings and greatly reduced the construction time, yet provided many challenges for the architects – particularly in coordinating new services with the existing structure.

The existing building was extended on two façades, strengthening its connection with the street corner and increasing the usable floor area on each level. The convex extension was built using a steel frame, wrapped in a highly efficient black aluminium curtain wall, manufactured by Scheldebouw.

Ground-floor plan

First-floor plan

Second-, third- and fourth-floor plan

Fifth-floor plan

Fig 2.80 Angel Centre Plans

Fig 2.81 Before – Angel Centre in the 1980s

Fig 2.82 After – Angel Building in 2011, architect Alford Hall Monaghan Morris

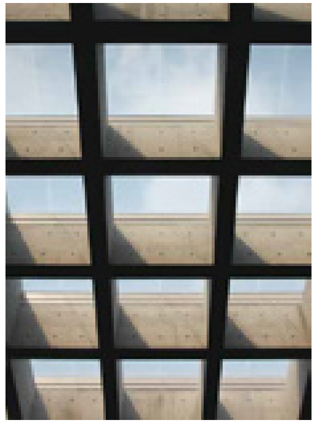


Fig 2.83 Roof lights in the concrete insertion allow light to flood the atrium space

Fig 2.84 The inserted concrete atrium provides a communal space at ground level and natural daylight for the offices above

A concrete insertion was made into the existing central service yard, creating an internal atrium with vertical circulation at either side. This insertion provided the means for new services to be distributed throughout the building, including hot water for heating and sanitary facilities from the two biomass boilers located at ground level. The atrium is characterised by a high-quality exposed concrete frame with an as-struck finish, and is naturally lit through an operable ETFE cushion covering. The atrium is a major exploit in the reinvention of the internal aesthetic and spatial quality; it creates communal spaces at ground- and first-floor level while ensuring good daylighting in the offices above.

At the junction between the new and old structures, pairs of columns were created; these remain structurally independent, but are mostly clad with a common lining. A fifth storey, built from steel, creates more usable office space and is set back from the main structure to create roof terraces.

Upon completion, the building achieved a BREEAM Excellent rating, proving that a highly energy-efficient building can be achieved from the reuse of an existing building, which ultimately prevented demolition. The Angel Building is a model for reinventing unused existing buildings – an essential future if carbon targets are to be met. Furthermore, it underlines an important reason for reusing existing buildings: it can reduce waste.

Fig 2.85 The steel frame, which extends from the existing concrete frame

1. White aluminium coping
2. Insulated double-glazed unit with white aluminium backing panel, white frit pattern and structural silicone bonding
3. White aluminium transom
4. Double-glazed unit: 8mm heat strengthened low iron glass, 16mm cavity, 12.6mm laminated annealed low iron glass with structural silicone bonding and white frit pattern
5. Insulated double-glazed unit with white aluminium backing panel, white frit pattern and structural silicone bonding
6. Black rainscreen
7. Black aluminium coping
8. Black horizontal aluminium extrusion
9. Black vertical aluminium extrusion
10. Insulated double-glazed unit with grey aluminium backing panel, grey frit pattern and structural silicone bonding
11. Black aluminium structural frame
12. Black vertical aluminium extrusion
13. Double-glazed unit: 8mm heat strengthened, low iron glass, 16mm cavity, 12.6mm laminated annealed low iron glass with structural silicone bonding
14. 3m-wide openable window
15. Light fitting
16. Canted window cill
17. Black insulated spandrel panel

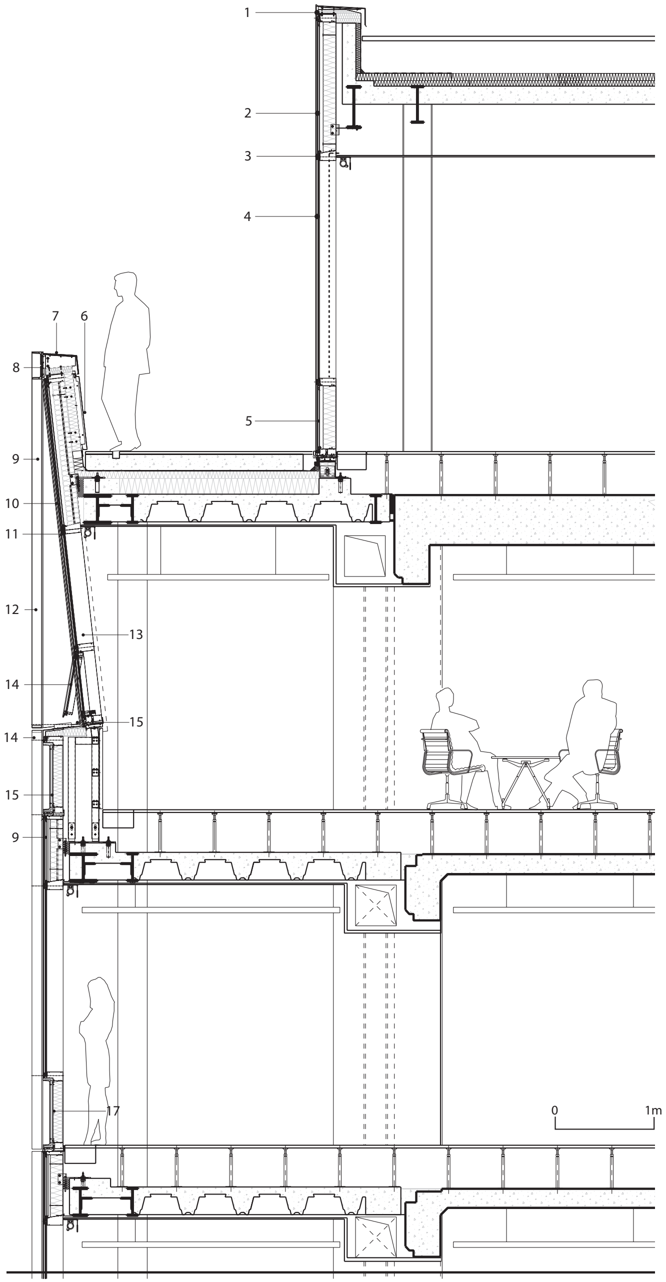


Fig 2.86 Detail of the new façade of the Angel Building

Park Hill, Sheffield: Architect Hawkins Brown and Studio Egret West, Completed 2013

Fig 2.87 Park Hill after the refurbishment of the first phase, designed by Hawkins Brown and Studio Egret West

Designed by Jack Lynn and Ivor Smith, architects for Sheffield City Council, and completed in 1961. This scheme comprised 495 flats and 500 maisonettes. Whole streets of people were transferred from terraced inner-city housing to Park Hill, meaning that everyone knew their neighbours. During its early years, Park Hill was a showpiece of social housing. In 1998, English Heritage gave it a Grade II* listing.

As part of the redevelopment, the existing concrete frame of Park Hill has been cleaned and repaired in damaged areas. Repairs were done by marking out a section around each damaged area and neatly cutting this out with high-pressure water jets. The exposed rebar was treated with an anti-carbonation coating and then covered with repair mortar.

The brickwork façade and single-glazed aluminium windows were arguably the most aesthetically and environmentally obsolete elements of Park Hill. The single-glazed aluminium windows were

Fig 2.88 Entrances to the apartments are lined in plywood with a corner window

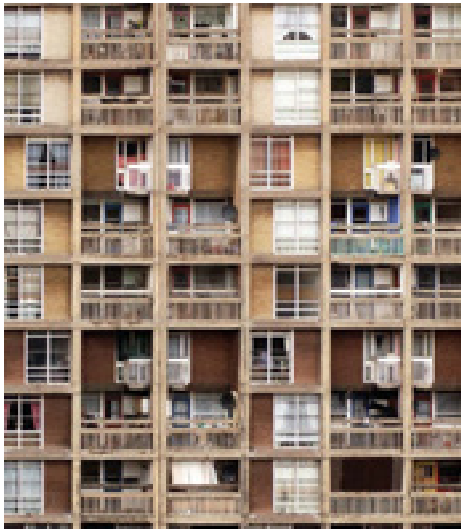


Fig 2.89 The original Park Hill façade, with brickwork infill and single-glazed units

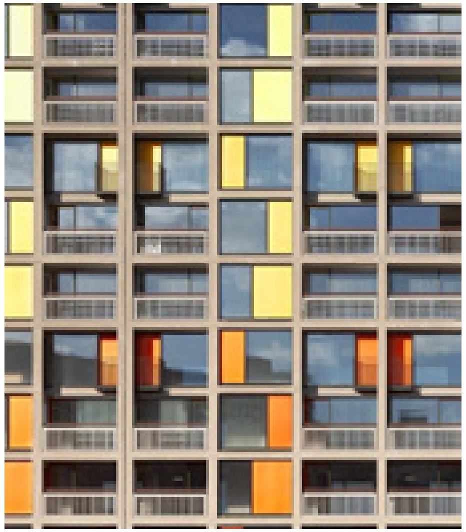


Fig 2.90 The Park Hill façade after refurbishment, with double glazing and coloured anodised aluminium infill panels

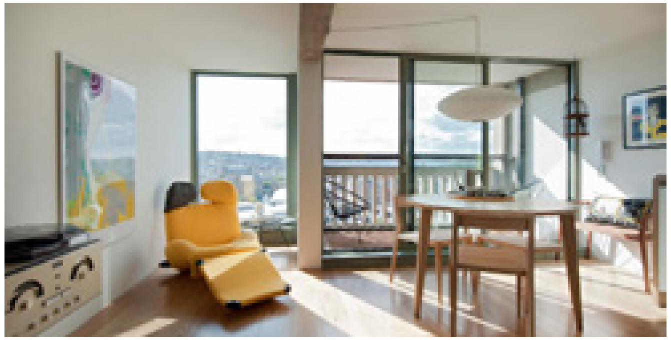


Fig 2.91 An internal view of a refurbished apartment in Park Hill

inadequately sealed with asbestos cord 'gaskets' – a common but poor specification at the time. The size of the openings has been increased, dramatically changing the internal spaces. Parts of the concrete frame have been left exposed internally, providing thermal mass to regulate the internal temperature.

The glazing system uses Everseal IG units in conjunction with a Kawneer architectural aluminium system, designed and installed for the project by SG Aluminium of Blackburn. A horizontal sliding window system with some fixed lights has been specified to offer maximum airflow for occupants' comfort, together with high security

and easy operation. Anodised aluminium infill panels have been used for their durability and low maintenance needs; the colour of the anodising varies in a gradient across the façade.

As well as saving an icon, Hawkins Brown identifies that by reinventing Park Hill, it has prevented the equivalent of four football stadia of materials being taken to landfill and that the embodied energy in the concrete frame is equivalent to three weeks' energy output from a power station.

Case Studies: Observation

As can be seen from these case studies, in all three types of approach – reglazing/refenestration, over-cladding and reinvention/deep retrofit – aluminium has a significant role in preserving the existing building fabric combined with the delivery of comfort and productive architecture, whilst significantly reducing the operational energy demands and delivering vital climate change impact savings.

Notes

1 See also Canadian Standard for Durability – CSA S478-95 (R2007) – *Guideline on Durability in Buildings*, which is used in LEED Canada.

2 Pacific Northwest National Laboratory for the US Department of Energy (2010), cited in Preservation Green Lab for the National Trust for Historic Preservation (2011), *The Greenest Building: Quantifying the Value of Building Reuse*, NTHP, Washington, DC, p. 92, available online at www.preservationnation.org/information-center/sustainable-communities/green-lab/lca/The_Greenest_Building_lowres.pdf (accessed February 2015).

3 Ibid.

4 For a list of member countries in the OECD, see: Organisation for Economic Co-operation and Development, *List of OECD Member countries: Ratification of the Convention on the OECD*, available at www.oecd.org/general/listofoecdmembercountries-ratificationoftheconventionontheoecd.htm (accessed February 2015).

5 Pike Research (2012) *Global Building Stock Database*, available online at www.navigantresearch.com/newsroom/worldwide-commercial-and-residential-building-stock-will-grow-to-182-5-billion-square-meters-by-2021 (accessed April 2015).

6 United Nations Population Fund, *Urbanization*, available online at www.unfpa.org/pds/urbanization.htm (accessed June 2012). During the Industrial Revolution, Britain transformed from having a predominately rural economy in 1801 to having over 50 per cent of the population living in cities by 1851, see Chapter Three.

7 United Nations (2013), *World population projected to reach 9.6 billion by 2050 – UN Report*, UN News, 13 June, available online at www.un.org/apps/news/story.asp?NewsID=45165#.UujsdGTFKDU (accessed February 2015).

8 M. Rechtin (2013), *Average age of U.S. car, light truck on road hits record 11.4 years, Polk says*, Automotive News, 6 August, available online at www.autonews.com/article/20130806/RETAIL/130809922/#axzz2qHCK0Lhe (accessed December 2013).

9 M. White (2013), *Keynote: Third Generation Light Weight Vehicle Architecture*, in M. Stacey (ed.) *Prototyping Architecture: The Conference Papers*, second edition, Riverside Architectural Press, Cambridge, ON, p. 391.

10 Note the original American spelling, aluminum, has been retained. For more information on inventive designs by Charles and Ray Eames, see: D. Murphy (ed.) (1997), *The Work of Charles and Ray Eames: A Legacy of Invention*, Abrams, New York.

11 Vitra (2012), *Sustainability Report 2012*, Vitra, Birsfelden, p. 8, available online at www.vitra.com/en-gb/corporation/sustainability (accessed December 2013).

12 *Concise Oxford English Dictionary* (2002), tenth edition, with addenda, Oxford University Press, Oxford.

13 B. Boardman, S. Darby, G. Killip, M. Hinnells, C. N. Jardine, J. Palmer and G. Sinden (2005), *40% House*, Environmental Change Institute, Oxford, p. 40, available online at www.eci.ox.ac.uk/research/energy/downloads/40house/40house.pdf. Including a citation of Office of the Deputy Prime Minister, *English House Condition Survey, 2001,* UK Data Archive [distributor], March 2009, SN: 6102, http://dx.doi.org/10.5255/UKDA-SN-6102-1 (both accessed February 2015).

14 Institution of Civil Engineers (2008), *Demolition Protocol 2008*, ICE, London, available online at www.ice.org.uk/Information-resources/Document-Library/Demolition-Protocol-2008 (accessed December 2014).

15 The ICE Demolition Protocol also proposes the use of **New Build Recovery Indexes [NBRIs]** as a guide to the potential recovery of components and materials 'once a building comes to the end of its useful life'. Institution of Civil Engineers (2008), *Demolition Protocol 2008*, ICE, London, p. 14, available online at www.ice.org.uk/Information-resources/Document-Library/Demolition-Protocol-2008 (accessed December 2014).

16 For further details about this project, see: The Future Builds with Aluminium, *Ballingdon Bridge*, available online at http://greenbuilding.world-aluminium.org/benefits/light-strong/ballingdon-bridge.html (accessed April 2015).

17 M. Stacey, 2011, *Concrete: a studio design guide*, RIBA Publishing, London, p. 223. 'Volume 1 Series 800 Specification for Highway Works Road Pavements - Unbound, Cement and Other Hydraulically Bound Mixtures, Amendment - November 2009, Department of Transport, clause 803 defines Type 1 fill as an unbound granular material for making road sub-bases formed of aggregate 28 mm to dust', available online at www.standardsforhighways.co.uk/mchw/vol1 (accessed April 2015).

18 M. Stacey (ed.) (2014), *Aluminium and Durability: Towards Sustainable Cities*, Cwningen Press, Llundain.

19 W. B. Trusty (2004), *Renovating vs. building new: the environmental merits*, in Organisation for Economic Co-operation and Development (ed.), *OECD/IEA Joint Workshop on Sustainable Buildings: Towards Sustainable Use of Building Stock*, OECD, Paris, p. 210, available online at www.oecd.org/governance/regional-policy/35896769.pdf (accessed January 2014).

20 Preservation Green Lab for the National Trust for Historic Preservation (2011), *The Greenest Building: Quantifying the Value of Building Reuse*, NTHP, Washington, DC, available online at www.preservationnation.org/information-center/sustainable-communities/green-lab/lca/The_Greenest_Building_lowres.pdf (accessed February 2015).

21 US Environmental Protection Agency Office of Solid Waste (1998), *Characterization of Building-Related Construction and Demolition Debris in the United States* (EPA530-R-98-010), EPA, Washington, DC, available online at www.epa.gov/epawaste/hazard/generation/sqg/cd-rpt.pdf (accessed April 2015). Clearly, there is a need for further research and data collection into demolition.

22 Preservation Green Lab for the National Trust for Historic Preservation (2011), *The Greenest Building: Quantifying the Value of Building Reuse*, NTHP, Washington, DC, p. xi, available online at www.preservationnation.org/information-center/sustainable-communities/green-lab/lca/The_Greenest_Building_lowres.pdf (accessed February 2015).

23 United Nations Educational, Scientific and Cultural Organization (1972), *Convention Concerning the Protection of the World Cultural and Natural Heritage*, Paris, available online at http://whc.unesco.org/en/conventiontext/ (accessed February 2015).

24 Swiss Centre for Life Cycle Inventories (2010), *Ecoinvent Database v2.2*, SCLCI, Switzerland, available online at www.ecoinvent.org/database/ecoinvent-version-2/ (accessed April 2015).

25 Preservation Green Lab for the National Trust for Historic Preservation (2011), *The Greenest Building: Quantifying the Value of Building Reuse*, NTHP, Washington, DC, p. viii, available online at www.preservationnation.org/information-center/sustainable-communities/green-lab/lca/The_Greenest_Building_lowres.pdf (accessed February 2015).

26 N. Hollister, K. Klerks and A. Wood (2011), *Tall buildings in numbers,* CTUB Journal, 3, pp. 54–55.

27 *The Skyscraper Center: The Global Tall Building Database of the Council on Tall Buildings and Urban Habitat*, www.skyscrapercenter.com/ (accessed January 2015).

28 M. Patterson, A. Martinez, J. Vaglio and D. Noble (2012), *New skins for skyscrapers: anticipating façade retrofit*, in A. Wood, T. Johnson and Q. Li (eds), *Asia Ascending: Age of the Sustainable Skyscraper City*, CTBUH, Chicago, IL, pp. 209–215.

29 Ibid., p. 214.

30 Ibid., p. 215.

31 U. M. J. Boin and J. A. van Houwelingen (2004), *Collection of Aluminium from Buildings in Europe: A Study by Delft University of Technology*, EAA, Brussels, available online at http://recycling.world-aluminium.org/uploads/media/_TUDelftBrochure2004.pdf (accessed April 2015).

32 J. A. van Houwelingen, U.M.J. Boin and M. A. Reuter (2004), *Aluminium in buildings: inventory and collection during demolition*, in E. Vázquez, C. F. Hendriks and G. M. T. Janssen (eds), *PRO 40: International RILEM Conference on the Use of Recycled Materials in Buildings and Structures, 8–11 November 2004, Barcelona, Spain*, RILEM/SAPL, Bagneux, p. 198.

33 CDM with Cascadia and R. W. Beck, Inc. (2010), *Chicago Waste Diversion Study*, Chicago Department of Environment, Chicago, IL, P3-10 and P3-11, available online at www.cityofchicago.org/dam/city/depts/doe/general/RecyclingAndWasteMgmt_PDFs/WasteAndDiversionStudy/WasteDiversionStudyReport2.pdf (accessed April 2015).

34 Green Building Information Gateway, *Credits*, available online at www.gbig.org/credits/7505 (accessed September 2014).

35 Harvard Green Campus Initiative (2006), *46 Blackstone Renovation Case Study*, Harvard Green Campus Initiative, Cambridge, MA, available online at http://green.harvard.edu/sites/green.harvard.edu/files/migrated_story_files//BlackstoneCaseStudy.pdf (accessed April 2015).

36 Commonwealth of Massachusetts Executive Office of Energy and Environmental Affairs (2013), *Massachusetts 2010–2020 Solid Waste Master Plan: Pathway to Zero Waste*, Commonwealth of Massachusetts, Boston, MA, available online at www.mass.gov/eea/docs/dep/recycle/priorities/swmp13f.pdf (accessed April 2015).

37 Ibid., p. 3, citing data provided by D. Allaway (2008), *Materials Management, Climate, and Waste: Making the Connections*, West Coast Forum on Climate Change, Waste Prevention, Recovery and Disposal, Oregon Department of Environmental Quality, 26 June (American spelling of aluminum).

38 Orange County Government (2002), *The Regulated Recyclable Material Ordinance*, Orange County Government, Hillsborough, NC, available online at www.co.orange.nc.us/recycling/documents/ordinance_doc.htm (accessed April 2015).

39 J. Tabor (1996), *Otto Wagner: Die Österreichische Postsparkasse*, Falter Verlag, Vienna, pp. 36–37; World Aluminium, *Statistics*, available online at www.world-aluminium.org/statistics/ (accessed January 2014).

40 Aluminium for Future Generations, *Global Metal Flow*, available online at www.recycling.world-aluminium.org/en/review/global-metal-flow.html (accessed March 2014).

41 *The Future Builds with Aluminium*, www.greenbuilding.world-aluminium.org/home.html (accessed March 2014); Recycle Now, *Cans*, available online at www.recyclenow.com/how_is_it_recycled/cans.html (accessed March 2014).

42 International Aluminium Institute (2014), *Global Aluminium Mass Flow*, IAI, London, 2014, available online at www.world-aluminium.org/media/filer_public/2014/06/19/global_aluminium_mass_flow.xlsx (accessed March 2015). For regional mass flow models, see www.world-aluminium.org/publications/.

43 C. Bayliss (2013), *International Energy Agency Global Industry Dialogue & Expert Review Workshop: Aluminium Sector*, IEA, 7 October, available online at www.iea.org/media/workshops/2013/industry/Session1_Aluminium_IAI_IEA_7Oct2013Workshop.pdf (accessed April 2015).
44 World Aluminium, *Statistics*, available online at www.world-aluminium.org/statistics/ (accessed January 2015).
45 For details of the eight stages of this process, see: Aluminium for Future Generations, *Refining Process*, available online at http://bauxite.world-aluminium.org/refining/process.html (accessed April 2015). For an analysis of specific energy savings of an alumina refinery process in China, see: L. Liu, L. Aye, Z. Lu and P. Zhang (2006), *Analysis of the overall energy intensity of alumina refinery process using unit process energy intensity and product ratio method*, Energy, 31(8–9), pp. 1167–1176.
46 World Aluminium, *Statistics*, available online at www.world-aluminium.org/statistics/ (accessed January 2015).
47 International Aluminium Institute (2014), *Environmental Metrics Report v1.1: Year 2010 Data*, IAI, London, available online at www.world-aluminium.org/media/filer_public/2015/04/16/environmental_metrics_report_v11_14th_apr.pdf (accessed April 2015).
48 Based on 2014 data. World Aluminium, *Statistics*, available online at www.world-aluminium.org/statistics/ (accessed January 2015).
49 Organisation for Economic Co-operation and Development (2004), *OECD/IEA Joint Workshop on Sustainable Buildings: Towards Sustainable Use of Building Stock,* OECD, Paris, p. 11, available online at www.oecd.org/governance/regional-policy/35896769.pdf (accessed January 2014).
50 International Aluminium Institute (2014), *Global Aluminium Mass Flow*, IAI, London, available online at www.world-aluminium.org/media/filer_public/2014/06/19/global_aluminium_mass_flow.xlsx (accessed March 2015).
51 European Aluminium Association, *EU Primary Aluminium Import Dependency*, available online at www.alueurope.eu/production-eu-primary-aluminium-supply/ (accessed April 2015).
52 International Organization for Standardization (2006), *ISO 14040:2006 Environmental Management: Life Cycle Assessment – Principles and Framework*, second edition, ISO, Geneva.
53 K. Simonen (2014), *Life Cycle Assessment*, Routledge, London.
54 G. F. Menzies, S. Turan and P. F. G. Banfill (2007), *Life-cycle assessments and embodied energy: a review*, Construction Materials 160 (CM4), p. 141.
55 J. Atherton (2007), *Declaration of the metals industry on recycling principles*, The International Journal of Life Cycle Assessment, 12(1), pp. 59–60.
56 Ibid.
57 S. Carlisle, E. Friedlander and B. Faircloth (2015), *Aluminium and Life Cycle Thinking*, Cwningen Press, Llundain.
58 C. Golden (2009), *Aluminium Recycling: An International Review* (thesis), Imperial College London, available online at http://warrr.org/785/1/13.27_IC_C_Golden_Masters_Thesis_2009.pdf (accessed February 2015).
59 P. Otis (2014), *Recycling is the primary energy efficiency technology for aluminum and steel manufacturing,* US Energy Information Administration, available online at www.eia.gov/todayinenergy/detail.cfm?id=16211# tabs_SpotPriceSlider-2 (accessed April 2015).
60 As stated in the Glossary, *primary energy* is an energy form found in nature that has not been subjected to any conversion or transformation process. It is energy contained in raw fuels, and other forms of energy received as input to a system. Primary energy can be non-renewable or renewable.
61 European Aluminium Association (2015), *European Aluminium Industry's Sustainability Roadmap to 2025*, EAA, Brussels, p. 11, www.alueurope.eu/#3rdPage (accessed April 2015).
62 European Aluminium Association (2013), *Environmental Profile Report for the European Aluminium Industry*, EAA, Brussels, available online at www.alueurope.eu/wp-content/uploads/2011/10/Environmental-Profile-Report-for-the-European-Aluminium-Industry-April-2013.pdf (accessed April 2015).
63 Preservation Green Lab for the National Trust for Historic Preservation (2011), *The Greenest Building: Quantifying the Value of Building Reuse*, NTHP, Washington, DC, p. 20, available online at www.preservationnation.org/information-center/sustainable-communities/green-lab/lca/The_Greenest_Building_lowres.pdf (accessed February 2015). See also: B. Lippke, J. Wilson, J. Perez-Garcia, J. Bowyer and J. Meil (2004), *Life-cycle environmental performance of renewable building materials*, Forest Products Journal, 54(6), pp. 8–19, available online at www.corrim.org/pubs/articles/2004/fpj_sept2004.pdf (accessed February 2015); US Department of Energy, *2010 Building Energy Data Book*, US Department of Energy, Washington, DC, 2010, available online at http://buildingsdatabook.eren.doe.gov/ (accessed February 2015).
64 Advisory Council on Historic Preservation (1979), *Assessing the Energy Conservation Benefits of Historic Preservation: Methods and Examples*, ACHP, Washington, DC, available online at www.achp.gov/1979%20-%20Energy%20Conserv%20and%20Hist%20Pres.pdf (accessed February 2015).
65 How the past is treated in LCAs requires further research and discussion.
66 G. Hammond and C. Jones (F. Lowrie and P. Tse (eds)) (2011), *Embodied Carbon: The Inventory of Carbon and Energy (ICE)*, BSRIA/Bath University.
67 Ibid., p. 78.
68 Ibid.
69 Ibid., p. 124. Figures are specific to the UK and have been rounded to whole numbers.
70 Ibid.
71 U. M. J. Boin and J. A. van Houwelingen (2004), *Collection of Aluminium from Buildings in Europe: A Study by Delft University of Technology*, EAA, Brussels, available online at http://recycling.world-aluminium.org/uploads/media/_TUDelftBrochure2004.pdf (accessed April 2015).
72 I. Z. Bribian, A. Aranda Usón and S. Scarpellini (2009), *Life cycle assessment in buildings: state-of-the-art and simplified LCA methodology as a complement for building certification*, Building and Environment, 44(12), pp. 2510–2520.
73 R. H. Crawford (2011), *Life Cycle Assessment in the Built Environment*, Routledge, London.
74 E. Trenton (2012), *The Application of Two Models of Life Cycle Assessment (LCA) for Transition to the Low-Carbon Economy: A Case Study in the Aluminum Industry* (thesis), *Theses and Dissertations*, Paper 791, Ryerson University.
75 US Department of Energy, *2010 Building Energy Data Book*, US Department of Energy, Washington, DC, 2010, available online at http://buildingsdatabook.eren.doe.gov/ (accessed February 2015); J. Marriott, H. S. Matthews and C. T. Hendrickson (2010), *Impact of power generation mix on life cycle assessment and carbon footprint greenhouse gas results*, Journal of Industrial Ecology, 14(6), pp. 919–928.
76 International Aluminium Institute (2007), *Life Cycle Assessment of Aluminium: Inventory Data for the Primary Aluminium Industry*, IAI, London; International Aluminium Institute (2013), *2010 Global Life Cycle Inventory Data for the Primary Aluminium Industry*, IAI, London, available online at www.world-aluminium.org/media/filer_public/2013/10/17/2010_life_cycle_inventory_report.pdf (accessed February 2015).
77 M. Stacey (ed.) (2014), *Aluminium and Durability: Towards Sustainable Cities*, Cwningen Press, Llundain, p. 272.
78 C. Morgan and F. Stevenson (2005), *Design and Detailing for Deconstruction*, SEDA Design Guides for Scotland, Issue 1, Glasgow, p. 4, available online at www.seda.uk.net/assets/files/guides/dfd.pdf (accessed November 2014).
79 B. Guy and N. Ciarimboli, *DfD: Design for Disassembly in the Built Environment: A Guide to Closed-Loop Design and Building*, City of Seattle, King County, WA, available online at www.lifecyclebuilding.org/docs/DfDseattle.pdf (accessed April 2015).
80 See, for example: G. Boothroyd and L. Alting (1992), *Design for assembly and disassembly*, CIRP Annals – Manufacturing Technology, 41(2), pp. 625–636.
81 See, for example: A. Desai and A. Mital (2003), *Evaluation of disassemblability to enable design for disassembly in mass production*, International Journal of Industrial Ergonomics, 32(4), pp. 265–281.
82 M. Patterson, A. Martinez, J. Vaglio and D. Noble (2012), *New skins for skyscrapers: anticipating façade retrofit*, in A. Wood, T. Johnson and Q. Li (eds), *Asia Ascending: Age of the Sustainable Skyscraper City*, CTBUH, Chicago, IL, pp. 209–215.

83 M. Stacey (ed.) (2014), *Aluminium and Durability: Towards Sustainable Cities*, Cwningen Press, Llundain.
84 C. Thormark (2002), *A low energy building in a life cycle: its embodied energy, energy need for operation and recycling potential*, Building and Environment, 37(4), pp. 429–435.
85 KieranTimberlake (2011), *Cellophane House™*, KieranTimberlake, Philadelphia, PA.
86 B. Bryson (2006), *The Life and Times of the Thunderbolt Kid*, Doubleday, New York, p. 145. See also p. 5, where Bryson observes that in the 1950s 'No country had ever known such prosperity. When [the Second World War] ended, the United States had $26 billion worth of factories that hadn't existed before the war, $140 billion in savings and war bonds just waiting to be spent, no bomb damages and practically no competition.' He continues: 'By 1951 … almost 90 per cent of American families had refrigerators and nearly three quarters had washing machines, telephones, vacuum cleaners and gas or electric stoves … Americans owned 80 per cent of the world's electrical goods, controlled two-thirds of the world's productive capacity, produced 40 per cent of its electricity, 60 per cent of its oil and 66 per cent of its steel. The 5 per cent of people on Earth who were Americans had more wealth than the other 95 per cent combined.'
87 M. Stacey (ed.) (2014), *Aluminium and Durability: Towards Sustainable Cities*, Cwningen Press, Llundain.
88 JC Bamford Excavators Ltd, *JCB Service Exchange*, available online at www.jcb.co.uk/reman, cited in Department for Business Innovation & Skills/Government Office for Science, *Future of Manufacturing: A New Era of Opportunity and Challenge for the UK – Summary Report*, The Stationery Office, London, available online at www.gov.uk/government/publications/future-of-manufacturing/future-of-manufacturing-a-new-era-of-opportunity-and-challenge-for-the-uk-summary-report (accessed April 2015).
89 Caterpillar, *Facts and Figures*, available online at www.caterpillar.com/sustainability/remanufacturing/facts-and-figures, cited in Department for Business Innovation & Skills/Government Office for Science, *Future of Manufacturing: A New Era of Opportunity and Challenge for the UK – Summary Report*, The Stationery Office, London, available online at www.gov.uk/government/publications/future-of-manufacturing/future-of-manufacturing-a-new-era-of-opportunity-and-challenge-for-the-uk-summary-report (accessed April 2015).
90 World Green Building Council (2009), *Six Continents, One Mission: How Green Building is Shaping the Global Shift to a Low Carbon Economy,* Toronto, CA, p.12 and p.17, available online at www.gbcsa.org.za/wp-content/uploads/2013/06/WGBC-Report-2009-Six-Continents-One-Mission.pdf (accessed April 2015).
91 Preservation Green Lab for the National Trust for Historic Preservation (2011), *The Greenest Building: Quantifying the Value of Building Reuse*, NTHP, Washington, DC, available online at www.preservationnation.org/information-center/sustainable-communities/green-lab/lca/The_Greenest_Building_lowres.pdf (accessed February 2015).
92 'The Advisory Board of architects for the United Nations Building consisted of N. D. Bassov of the Soviet Union, Gaston Brunfaut (Belgium), Ernest Cormier (Canada), Le Corbusier (France), Liang Seu-cheng (China), Sven Markelius (Sweden), Oscar Niemeyer (Brazil), Howard Robertson (United Kingdom), 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 proposal were merged together creating a hybrid project named 42G.' See Chapter Three *Aluminium Pioneers* in M. Stacey (ed.) (2014), *Aluminium and Durability: Towards Sustainable Cities*, Cwningen Press, Llundain.
93 P. J. Arsenault (2013), *More than one way to skin a building,* Architectural Record, May, available online at http://continuingeducation.construction.com/article.php?L=352&C=1090 (accessed February 2015).
94 Ibid.
95 R. J. Nacheman (2006), *The Empire State Building: façade evaluation and repair of an engineering landmark*, Structure Magazine, 42, pp. 39–43, available online at www.structuremag.org/wp-content/uploads/2014/09/Empire-State-Building1.pdf (accessed February 2015).
96 American Architectural Manufacturers Association Aluminum Material Council, *The Aluminum Advantage*, AAMA Aluminum Material Council, Schaumburg, IL, pp. 38–39, available online at www.aamanet.org/upload/file/ AMC_Course.pdf (accessed December 2013).
97 A. J. Brookes and C. Grech (1990), *The Building Envelope*, Butterworth Architecture, Oxford, p. 80. This book prepared within my practice was predominately written by Alan Brookes and illustrated by Chris Grech.
98 I. Ijey (2011), *Guy's Hospital Tower refurbishment: nurse, the screens*, Building.co.uk, 8 April, available online at www.building.co.uk/guys-hospital-tower-refurbishment-nurse-the-screens/5015789.article (accessed February 2015).
Also refer to the ICE Demolition Protocol, Institution of Civil Engineers (2008), *Demolition Protocol 2008*, ICE, London, available online at www.ice.org.uk/Information-resources/Document-Library/Demolition-Protocol-2008 (accessed December 2014).
99 Allford Hall Monaghan Morris, *Angel Building*, available online at www.ahmm.co.uk/projectDetails/61/Angel-Building?sub=description (accessed January 2014).
100 Ibid.

case study: a zone of change

Case Study: A Zone of Change

The basic thesis of this chapter is that Britain urbanised between 1801 and 1851. During the Industrial Revolution, Britain transformed from having a predominately rural economy in 1801 to having over 50 per cent of the population living in cities by 1851. As observed in Chapter Two, since 2008, over half of humankind now lives in cities.[1]

Examination of the case study zone of change starts in 1851 in a part of London yet to be urbanised. South London cannot stand in for the current developing world, but it is a good surrogate considering the absence of systematic collection of data on demolition throughout the world. This zone includes award-winning aluminium-rich buildings under threat of demolition and the widespread use of aluminium in new-build developments, such as for windows. The aim of this zone of change case study is to illustrate how cities change and to reveal the timescales for the potential release of aluminium from architecture and infrastructure by demolition and reconstruction. Zone of change studies can be undertaken in any region of the world and especially in zones of rapid urbanisation.

Fig 3.1 The Pilot Inn, built in 1801, alongside a terrace of brick houses are the oldest buildings retained on the Greenwich Peninsula

Fig 3.2 Greenwich Peninsula, c1872

Fig 3.3 2015 Ordinance Survey Map of Greenwich Peninsula

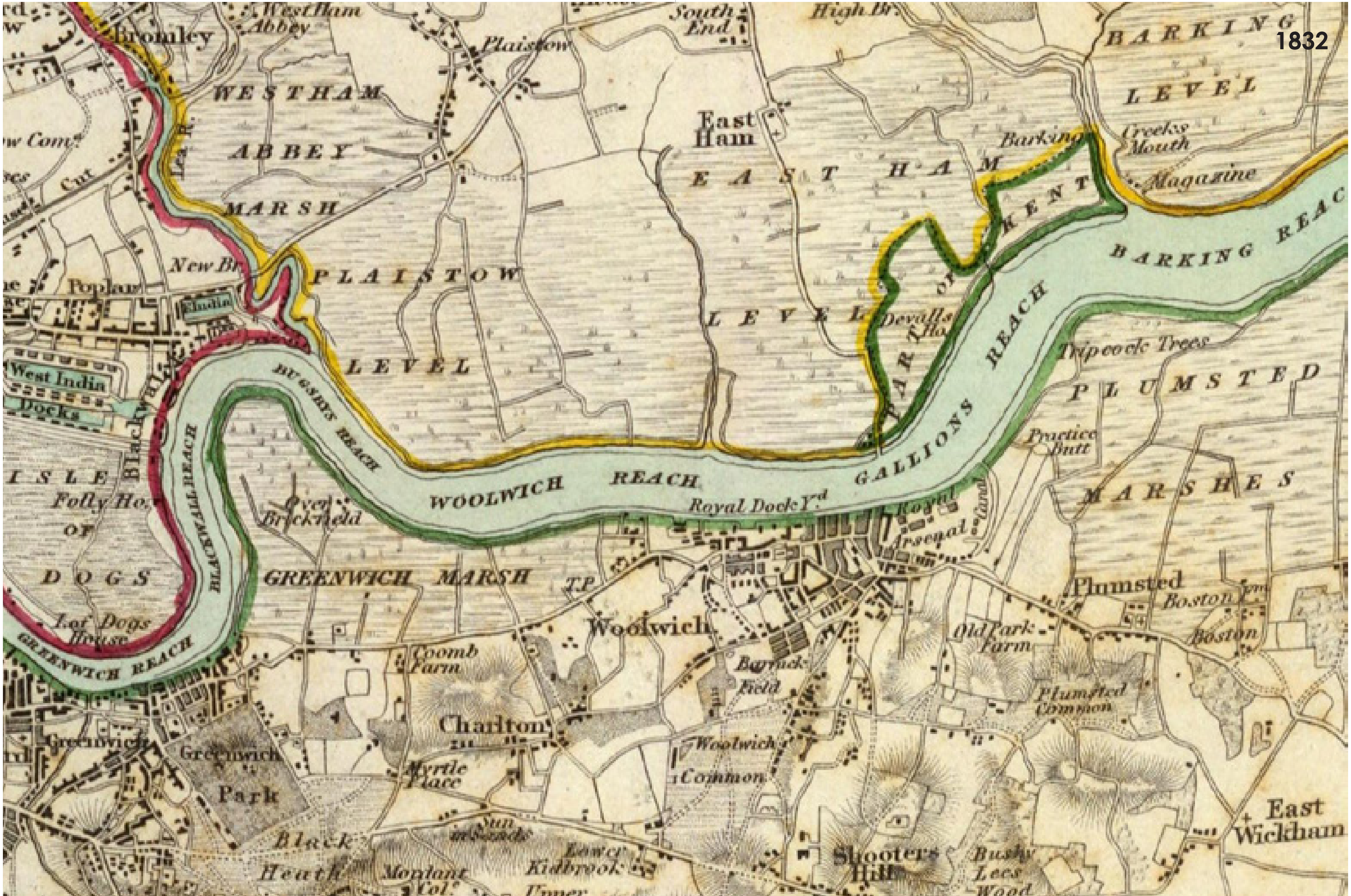


Fig 3.4 1832 London map showing Greenwich Marsh

To examine how cities change over time, a part of London was selected. This is centred on where the River Thames rounds Blackwall Point, and the study is primarily focused on the south bank part of the Royal Borough of Greenwich. This location, between Greenwich to the west and Woolwich downriver to the east, was selected as it has been a zone of significant change in terms of use, construction and demolition over the past 150 years.

In 1870, although Britain had sustained the Industrial Revolution for about 70 years, Greenwich Marshes and the south bank of the Thames above Woolwich Road was predominantly a system of agricultural fields.[2] The land was owned by Morden College, who ran almshouses in London, and from the middle of the nineteenth

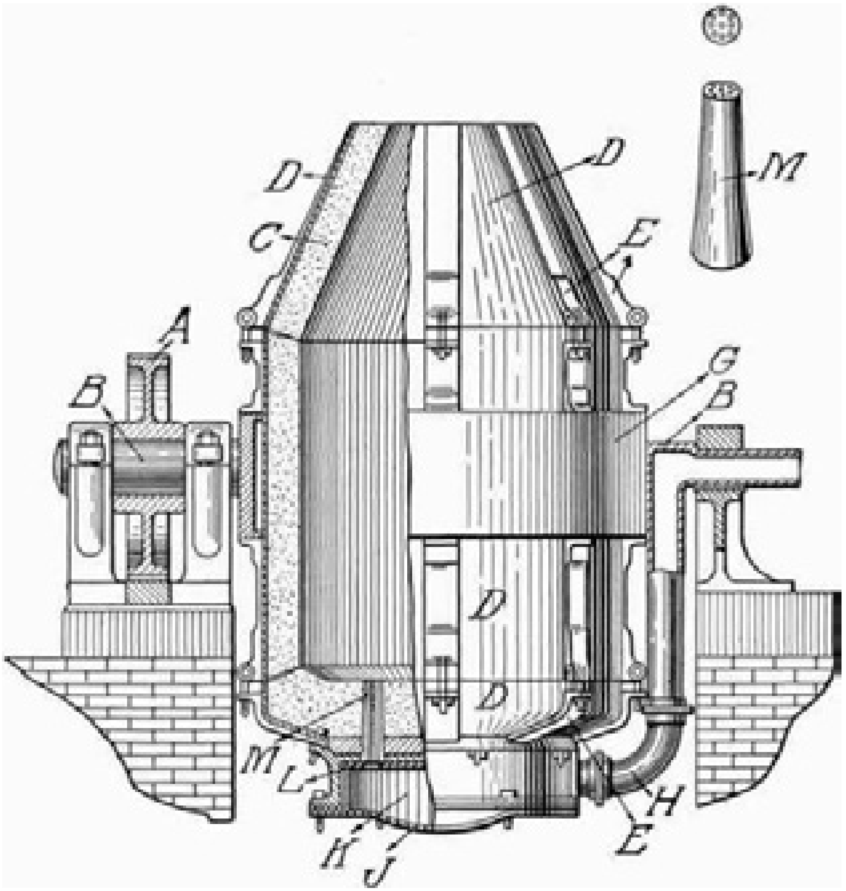


Fig 3.5 A Bessemer converter used for the mass production of steel, patented in 1856

century it sold plots on the peninsula to industry. By 1870, industry was starting to become established on the peninsula, notably the Electric Telegraph Company Works; the third and fourth successful transatlantic telegraph cables of 1865 and 1866 were manufactured in this works. Further north was Henry Bessemer's Steel Works; he invented the Bessemer converter, patented in 1856, which enabled the mass production of steel. He opened this factory on the Thames to serve the shipbuilding industry. Also on Blackwall Reach was Henry Blakeley's Ordnance Works. Other industrial buildings on the peninsula included two chemical works and a grinding mill.[3]

Fig 3.6 1865 Transatlantic Telegraph Cable Memorial, photographed early 2015

Fig 3.7 1870 OS Map of Greenwich Marshes

The wharf at Bugsby's Reach was served by a dedicated freight railway line, the norm for most industries at this time, which branched off the railway line south of Woolwich Road, which linked London Bridge and Kent. This was an extension of the first railway line built in London, from London Bridge to Greenwich. The London and Greenwich Railway opened in 1836, reaching Greenwich in 1838.[4] The line linking Greenwich with Kent via Charlton was completed in 1878, meeting the North Kent Line just west of Charlton.[5] The land south of this railway line, lying between the Navy in Greenwich and the Army in Woolwich, was fields and woods, with a few high-status houses including Charlton House, a fine Tudor mansion that rivals Hampton Court in west London. The presence of the railway did not directly lead to house construction in this area, at this time. An exception to this pattern of use was sand extraction from a pit south of the railway line in Charlton. It is reasonable to suggest that little or no demolition had taken place to construct the architecture and infrastructure in this zone of change by 1870. The area was classified as part of the county of Kent and not part of London.

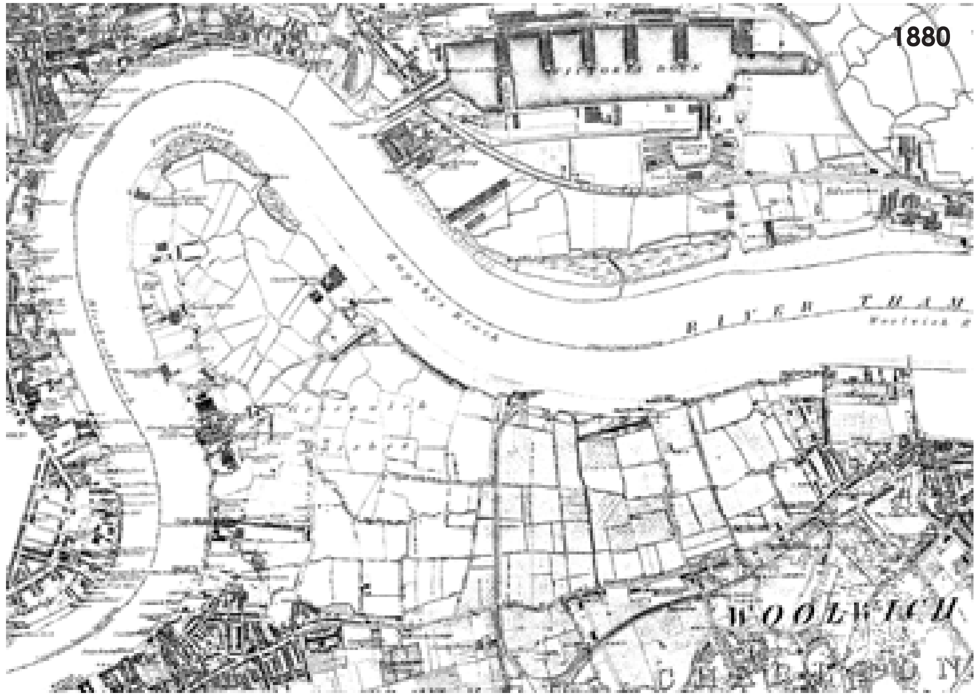


Fig 3.8 1880 OS Map of Greenwich Marshes

Over the next ten years, little changed on Greenwich Marshes; however, 12 years later, in 1892, the construction of the Blackwall Tunnel under the Thames began. This single-bore tunnel, which was constructed over five years by 800 men at a cost of £1.4 million, opened in 1897. The East Greenwich Gasworks was built on Bugsby's Reach between 1881 and 1886. This was the last coal gasworks to be built in London.

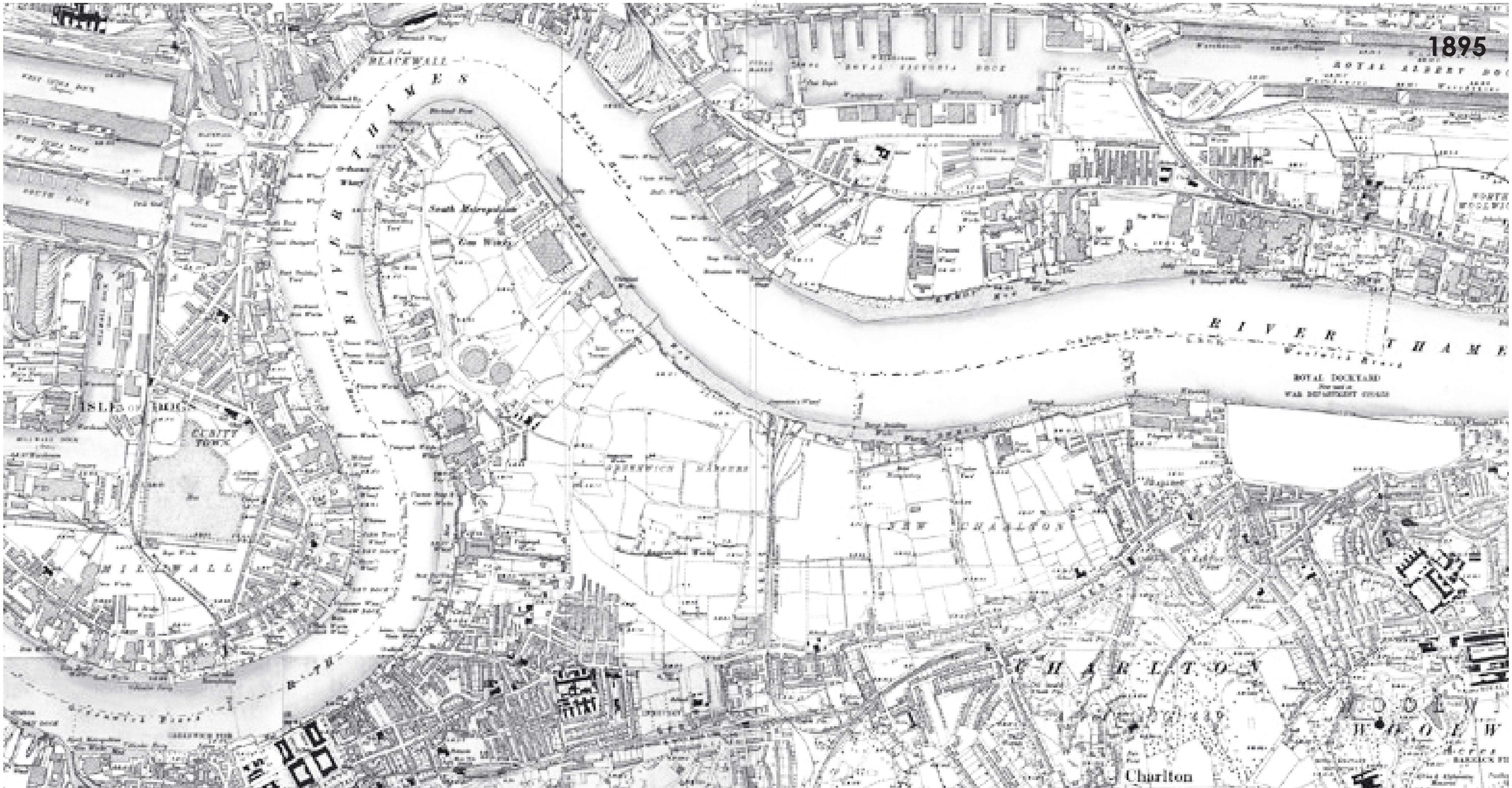


Fig 3.9 1895 OS Map of Greenwich Marshes

During the 1890s, Blackwall Point Power Station was built. Following the creation of the London County Council [LCC] in 1889 and the 1899 London Government Act, metropolitan boroughs were established in 1900, including Greenwich and Woolwich – and thus this area became part of London.

The Maryon-Wilson family gave the sand pits in Charlton, together with Hanging Wood, to the LCC in 1891. Gilbert's Pit continued to be used for the extraction of sand until the Second World War; unlike the adjacent sand pit that became Maryon Park, this is now a nature reserve and a Site of Special Scientific Interest [SSSI]. Hanging Wood was renamed Maryon Wilson Park after the Second World War.

Fig 3.10 The future Maryon Park, c1896

Fig 3.11 1910 OS Map of Greenwich Marshes

By 1910, wharfs and industry occupied the entire south bank of the Thames between Blackwall Reach and Bugsby's Reach, including the Thames Soap and Candle Works, the Greenwich Linoleum Works and the Delta Metal Company Works, which produced cast and extruded bronze. Both animal feed and asbestos were also produced on the peninsula, which was starting to be dominated by the gasworks, served by wharfs on the eastern side. The works were also served by extensive railway lines linked to the freight lines that still serve Christie's Wharf. The centre of the peninsula was open and included a football ground, a church and a cricket ground. Housing had been built along Woolwich Road and the land up to the formerly discrete village of Charlton was filled out with red-brick houses built during the reign of Edward VII. These houses were built primarily for the skilled workingmen employed in the many industries that bordered the river. The name Greenwich Marshes persisted but it was mostly now allotment gardens. To the east of the branch line, New Charlton had been established and included an LCC Tramways maintenance depot and Greenwich Metal Works. Other industries included glass bottle manufacture and a print works. New Charlton was also the site of two schools and some terraced housing.

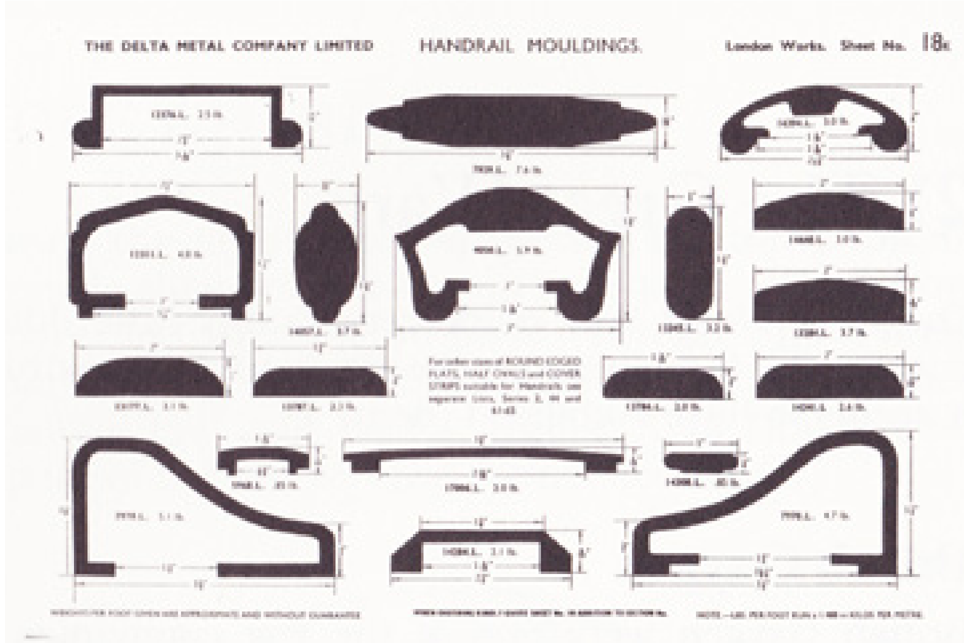


Fig 3.12 Delta Metals bronze extrusions

Fig 3.13 East Greenwich Gasworks, view from Tunnel Avenue, 1910

Fig 3.14 1920 OS Map of Greenwich Marshes

Little had changed in the area by 1920; presumably this lack of development can be explained by the First World War (1914–18). Even by 1930, the area was largely unchanged; however, the football ground next to the gasworks had gone and the industry in New Charlton had expanded, although some allotment gardens remained. By the start of the Second World War, the mix of industry and housing was substantially unchanged in this part of London. Although specific buildings were lost to German bombing during the Blitz, the pattern of uses continued after the war.

Fig 3.15 1930 OS Map of Greenwich Marshes

Fig 3.16 A London tram approaching the Blackwall Tunnel, c1930

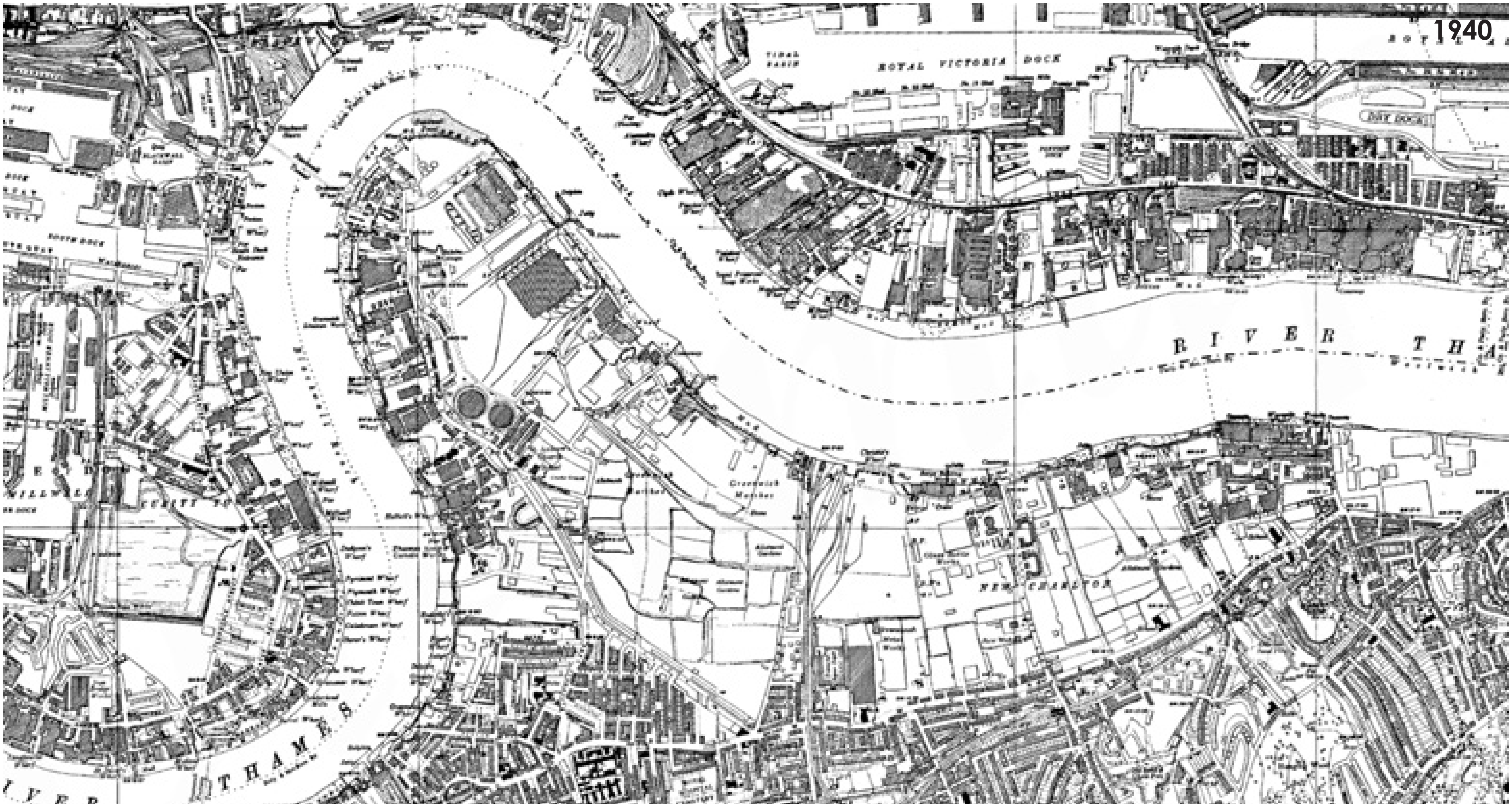


Fig 3.17 1940 OS Map of Greenwich Marshes

Fig 3.18 An air raid spotter at the Valley: Charlton vs Arsenal, 1940

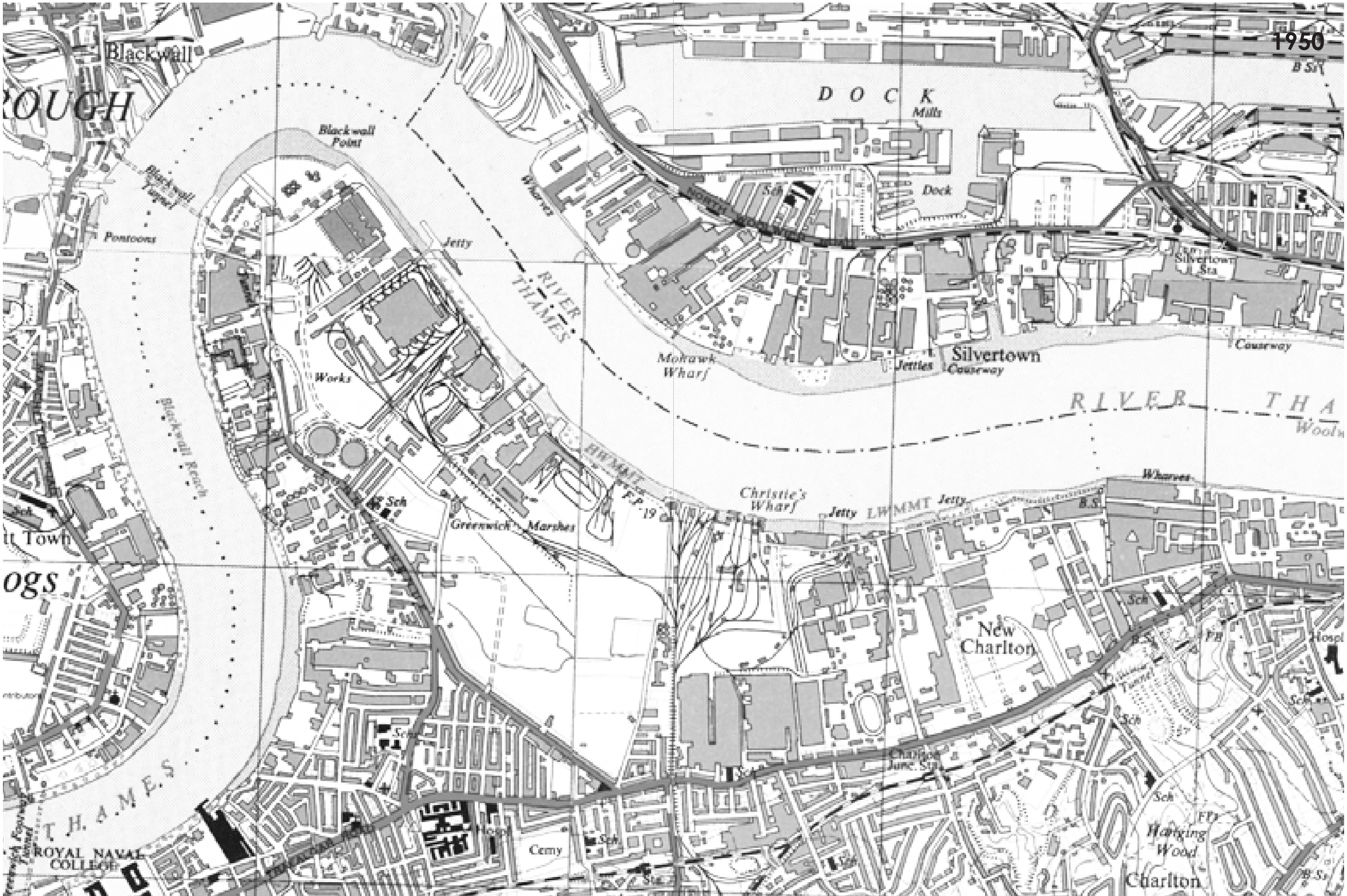


Fig 3.19 1950 OS Map of Greenwich Marshes

By 1950, the gasworks had expanded and now extended to Blackwall Point Power Station. Wharfs had replaced jetties on Blackwall Reach and further industry had been built, largely as infill projects. The south of the peninsula remained allotment gardens. Even in 1960 these allotments persisted. However, New Charlton was now almost fully occupied by industry from the river to Woolwich Road, with the exception of a greyhound-racing stadium, tennis courts and a bowling green – not quite a monoculture of industry. The LCC Tramways depot was still there but would soon no longer serve trams; the last tram in London ran in 1952, until the Croydon Tramlink opened in 2000. The nineteenth-century Blackwall Point Power Station was replaced by a new power station during the 1950s.

Fig 3.20 LCC's Central Tram Depot, Charlton; it later became a factory for Airfix GMR before it was demolished in the 1990s

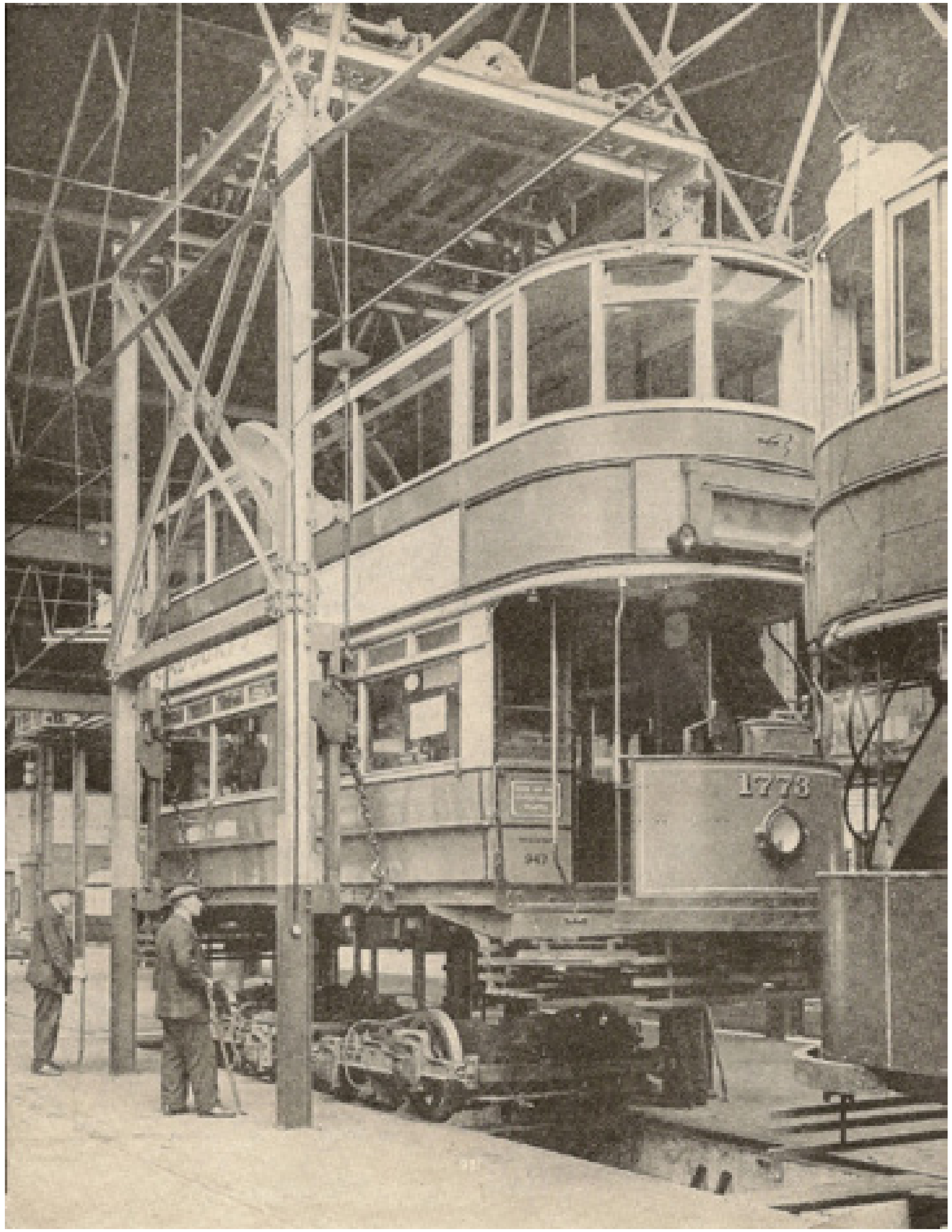


Fig 3.21 1960 OS Map of Blackwall Tunnel Peninsula

In 1965, the Greater London Council replaced the LCC and the Metropolitan Boroughs of Greenwich and Woolwich merged to become the London Borough of Greenwich. A second Blackwall Tunnel was completed in 1967 with the aim of relieving traffic congestion. Although it was planned before the Second World War, construction did not commence until 1960. Otherwise, by 1970, the pattern of industry and other uses was substantially unchanged. The gasworks had expanded south; it now covered almost 1km^2 (240 acres). The allotment gardens had largely become a sports ground, with a small number of allotments remaining. The old tram depot had become a warehouse but its footprint was unchanged. On Blackwall Reach, Victoria Wharf had become Victoria Deep Water Terminal, handling containers. To create this, most of the existing buildings had been demolished; however, the site would prove too small for this technology. In East Greenwich, a large general hospital had been built to the south of Woolwich Road on the site of an early set of hospital buildings, which was established as the Greenwich and Deptford Union Workhouse in the nineteenth century.

Fig 3.22 Croydon Tramlink in February 2012, outside East Croydon Station, architect Brookes Stacey Randall Fursdon

Employment in Manufacturing in the United Kingdom

In 1870, 42 per cent of the British working population was employed in manufacturing. This rose to 45 per cent by 1910 and reached almost 50 per cent by 1950. By 1973, the proportion of the British working population employed in manufacturing had fallen slightly to 46 per cent; however, a dramatic decline then began and by 1993 the proportion had fallen to only 25 per cent.[6] By 2004, only 10 per cent of the working population in London was employed in manufacturing, with over 30 per cent employed in service industries such as banking. In 2014, the proportion of people working in manufacturing in London had fallen to 2.4 per cent. In the UK, the East Midlands had the highest level of employment in this sector, at 12.3 per cent.[7]

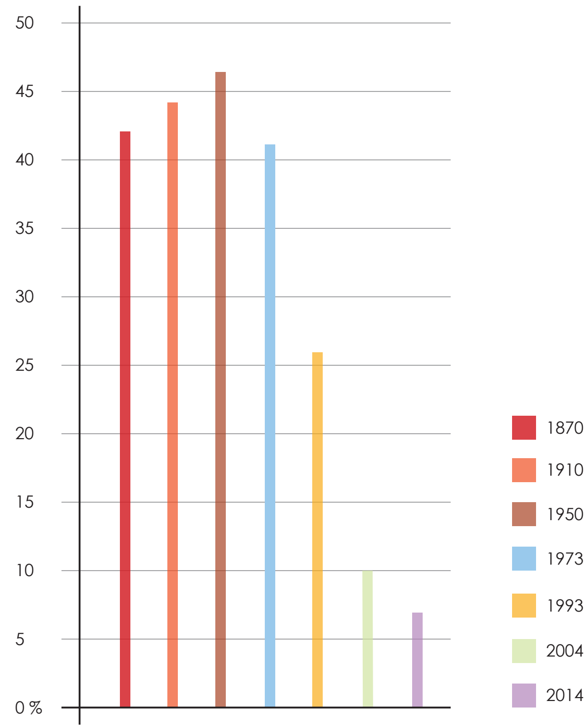


Fig 3.23 Percentage of total employment in the UK manufacturing industries, 1870–2014

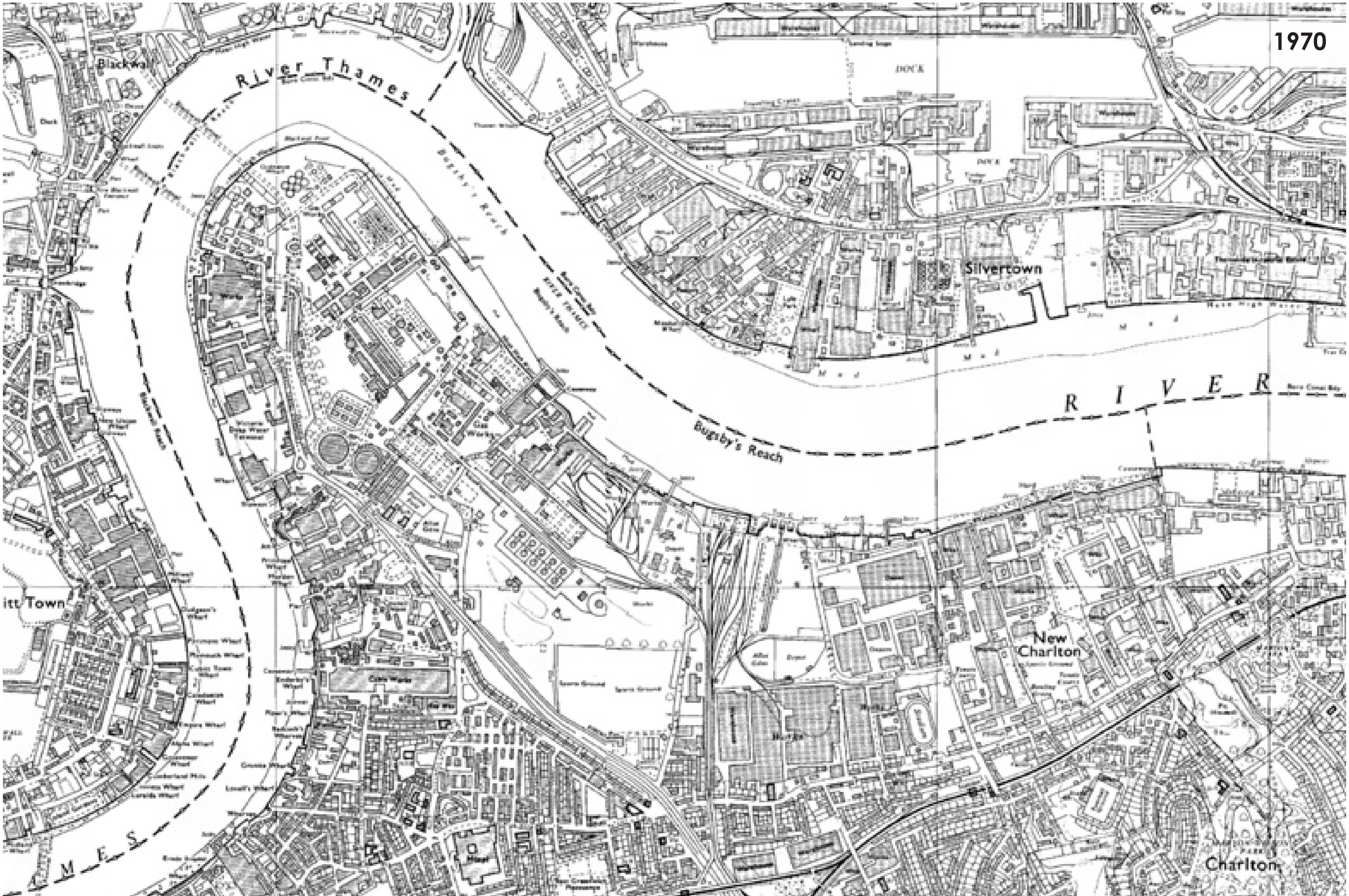
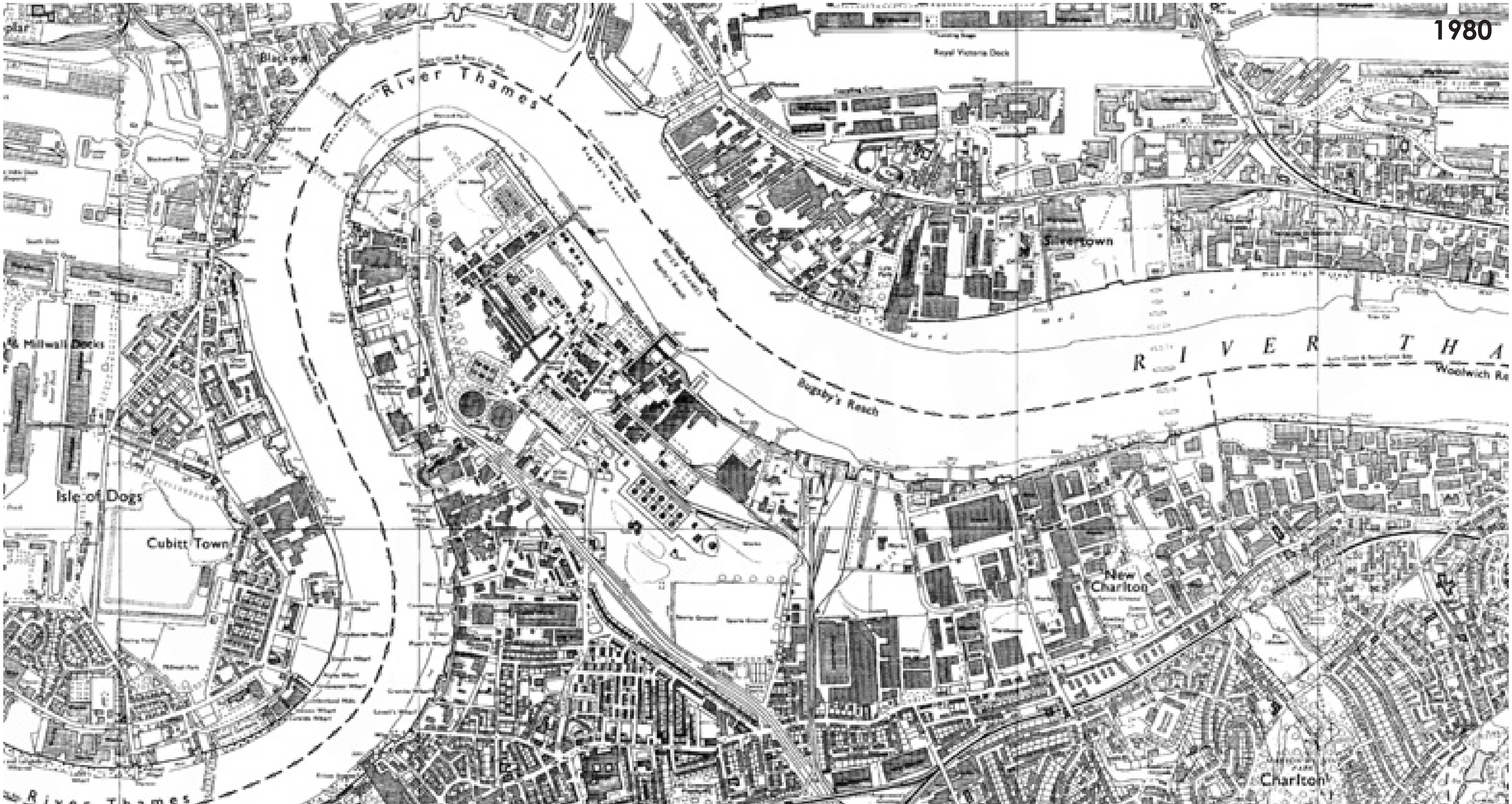


Fig 3.24 1970 OS Map of Blackwall Tunnel Peninsula



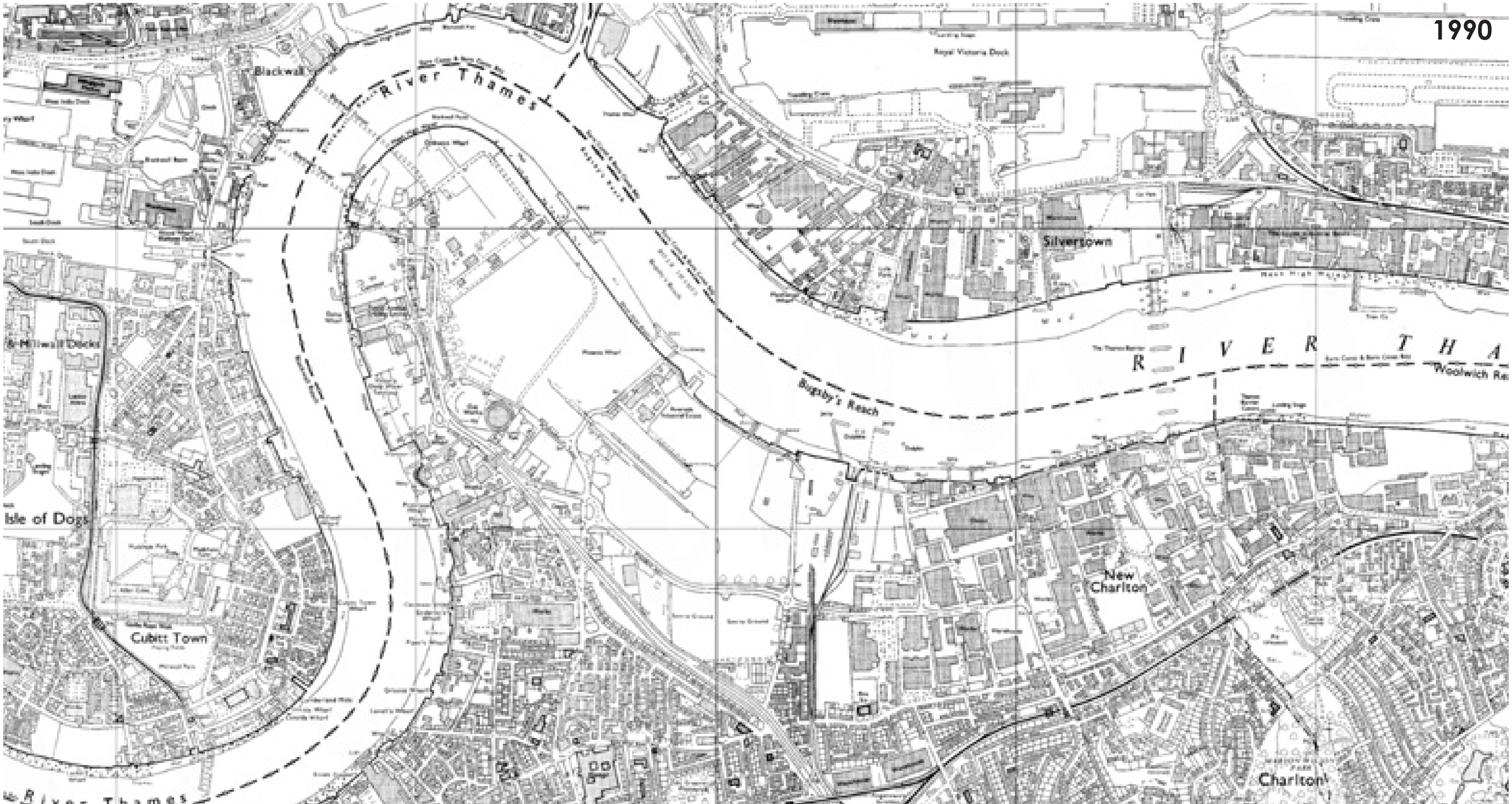
In 1965, natural gas was discovered under the North Sea. The first town to be converted to natural gas was Burton-upon-Trent in 1968 and this national programme was completed by 1976.[8] Thus, by the beginning of the 1980s, the old coal gasworks on the Blackwall Tunnel peninsula was largely obsolete and Ordnance Wharf at Blackwall Point was empty. Many of the industrial buildings were still standing; however, the level of usage had declined, with some converted to warehouses. The greyhound-racing stadium had been replaced by a building labelled as a warehouse; however,

Fig 3.25 1980 OS Map of Blackwall Tunnel Peninsula

this was one of the first of the large out-of-town shops. The 1980 Local Government, Planning and Land Act granted powers to create Urban Development Corporations [UDCs] and Enterprise Zones. This law, brought in by the Conservative government led by Margaret Thatcher, made it very difficult for local authorities with established town centres to resist various forms of out-of-town shopping development, from major centres to a sprawl of low-cost shopping sheds.

The construction of the Thames Barrier commenced in 1978 and was substantially completed by 1982 when the barrier became operational. This tidal defence barrier cost £534 million and was officially opened by Queen Elizabeth II in 1984. The freight-only branch line continued to serve the wharf on Bugsby's Reach and a siding still entered the gasworks. In 1981, the Blackwall Point Power Station closed. In 1985, Charlton Athletic Football Club left the Valley, which had been bought by speculators to build a supermarket. However, after significant local protest, this development was blocked and the club returned to a rebuilt ground in 1992.

Fig 3.26 Thames Barrier, photographed 2013



By 1990, much of the Blackwall Tunnel peninsula was empty and heavily contaminated land. The gasworks had been demolished, except for one gasholder that regulated the flow of natural gas (there had been two). The land is still owned by British Gas. On Blackwall Reach, some of the industrial buildings had been demolished but Tunnel Refineries (owned by Tate & Lyle) was still functioning next to the entrance to the Blackwall Tunnel. At the base of the peninsula, a dual-carriageway road, Bugsby's Way, had been built by Greenwich Council as an act of regeneration.

Fig 3.27 1990 OS Map of Blackwall Tunnel Peninsula

This stimulated the construction of a series of out-of-town shops, including Asda, during the 1990s, following the demolition of former industrial or warehouse sites. This process continued into the 2000s.

St Andrews Church, which was built on the peninsula in 1902, was demolished in 1984. It is also pertinent to note that only one of the two sports grounds that were visible in 1980 had survived. The ground at the base of the peninsula remained, but by 1999 this too had been repurposed as out-of-town shopping. Before the gasworks site was regenerated, recreational space had been lost in this part of London.

Fig 3.28 Architect Foster + Partners' North Greenwich Transport Interchange has an aluminium standing-seam roof

In 1997, regeneration agency English Partnerships purchased 1.21km² (300 acres) of derelict land on the Blackwall Tunnel peninsula. The approaching Millennium proved a strong driver for regeneration of the peninsula, which was renamed Greenwich Peninsula. Earlier in the 1990s, the London Borough of Greenwich successfully lobbied London Underground to bring the Jubilee line under the top of the peninsula, thus creating a new underground station in south-east London. The beginning of a very significant improvement of the connectivity of this area, the Docklands Light Railway, reached Woolwich in 2009, which will also be served by Crossrail in 2019. This decision preceded the master planning of the peninsula and the decision to build the Millennium Dome. The Jubilee line station at North Greenwich, designed by Alsop & Störmer, opened in May 1999. Above this is the North Greenwich Transport Interchange (a bus station) designed by Foster + Partners, which has an aluminium standing-seam roof. Also in 1999, Greenwich Yacht Club was relocated to new premises on Bugsby's Reach and a Holiday Inn opened on Bugsby's Way, with the Odeon multiplex cinema and out-of-town shops opening on the site south of Bugsby's Way at the base of the peninsula. This included a day-lit supermarket designed by Chetwoods for Sainsbury's. This 5,110m² supermarket aimed to be 50 per cent more environmentally friendly than a conventional supermarket. The Millennium store has been described as looking 'like a shiny aluminium-clad spaceship perched on two grass feet'.[9] It was built entirely from sustainable materials, including an aluminium standing-seam roof.[10] The first supermarket to achieve a BREEAM Excellent rating, it won the 2000 RIBA Sustainability Prize, was nominated for the Stirling Prize and won an Aluminium Imagination Award in 2001. Michael Evamy of the *Independent* observed that 'Sainsbury's Greenwich is the most carefully designed supermarket in the world, ever'.[11] In 2014, it was selected as one of the Twentieth Century Society's 100 Buildings for 100 Years.

Fig 3.29 Sainsbury's Millennium store, Greenwich Peninsula, 1999, designed by Chetwoods

Fig 3.30 Sainsbury's entrance with the Dome in the distance

Fig 3.31 Aerial view of Greenwich Peninsula, 2000

The Millennium Dome, designed by the Richard Rogers Partnership, was completed and fitted out with the Millennium Exhibition just in time for Millennium Eve. Designed in collaboration with engineers BuroHappold, the Dome is a very elegant enclosure of space costing £43 million.[12] Often a figure of £758 million is quoted for this project; however, this includes the infrastructure and remediation of the contaminated land of the former gasworks, an area of 1.21km^2 (300 acres). Having welcomed over 6 million visitors in 2000, the Dome closed and was acquired by the Anschutz Entertainment Group. In a £6 million sponsorship deal with Telefónica Europe, the venue was renamed the O_2. The internal fit-out cost £600 million and it reopened in 2007. Robert Kronenburg has described it as a very successful example of rock and roll architecture.[13]

In 2000, the only other new construction on the Greenwich Peninsula was the David Beckham Football Academy, which was considered to be temporary use, and housing designed by HAT based on an outline design by Ralph Erskine. This was situated at the end of the central park, which was the core of the enhanced landscaping of the peninsula commissioned and maintained by English Partnerships. Both the hard and soft landscape was well designed. The overall master plan of Greenwich Peninsula, designed by the Richard Rogers Partnership, proved very successful. On the western side of the Blackwall Tunnel approach road, the following industries persisted: Alcatel, Tunnel Refineries, which closed in 2009, and two large aggregate wharfs. The oldest building retained on the Greenwich Peninsula is the Pilot Inn, built in 1801 with a small terrace of brick houses. In 2001, the Millennium School and Health Centre, designed by Edward Cullinan Architects, was completed next to the roundabout at the end of Bugsby's Way and John Harrison Way.

Fig 3.32 The Millennium Dome, architect Richard Rogers Partnership

Fig 3.33 Aerial view of North Greenwich Transport Interchange and the Millennium Dome in 2000

Fig 3.34 Extruded aluminium louvres clad the service pods – a total of 12 are located around the base of the Dome's canopy

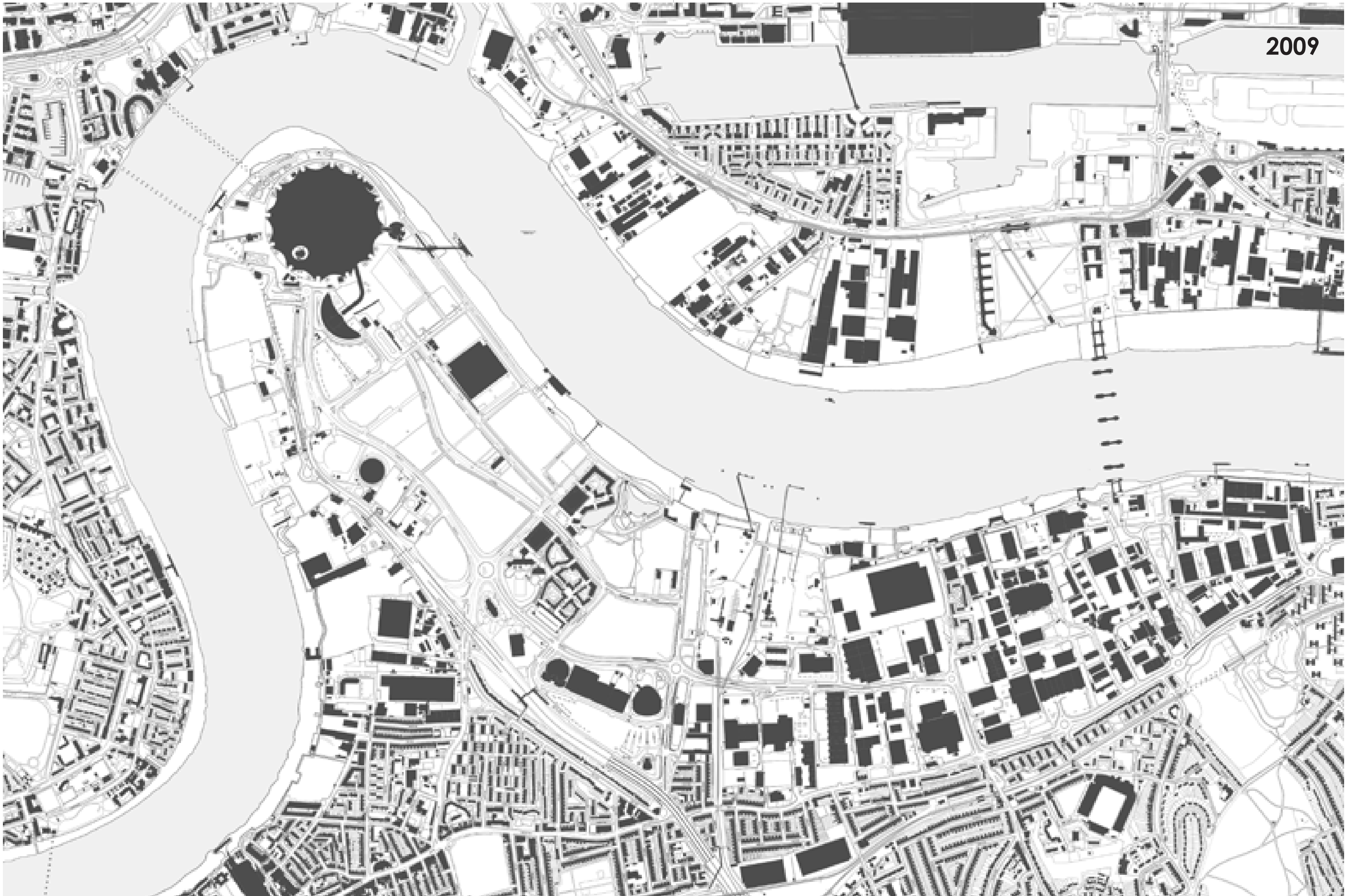


Fig 3.35 2009 OS Map of Greenwich Peninsula

Ravensbourne College, designed by Foreign Office Architects and clad in tessellated anodised aluminium panels, was completed ready for September 2010. Alongside this college, which can be converted to offices, are two office buildings of a similar scale designed by Terry Farrell & Partners, with shops and cafés on the ground floor facing onto Peninsula Square. New housing on the Greenwich Peninsula appears to have been delayed by the banking crisis of 2008, as by late 2011 the only new housing was the City Peninsula apartments with three-storey family homes facing the Thames at Bugsby's Reach.

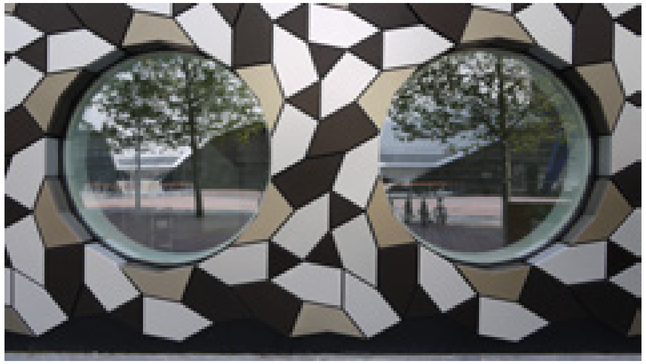


Fig 3.36 Tesselated anodised aluminium cladding panels, silver, bronze and champagne anodising, of Ravensbourne College

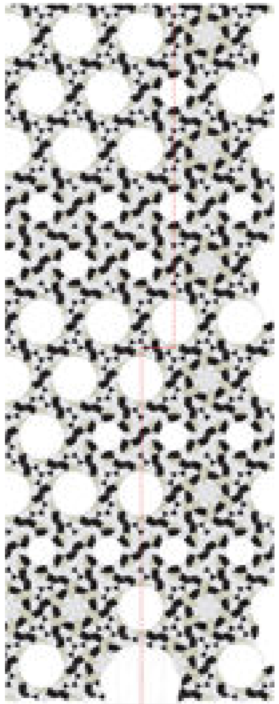


Fig 3.37 Drawing of tesselated aluminium cladding

Fig 3.38 Ravensbourne College designed by Foreign Office Architects, 2010

Fig 3.39 Ravensbourne College facing Peninsula Square

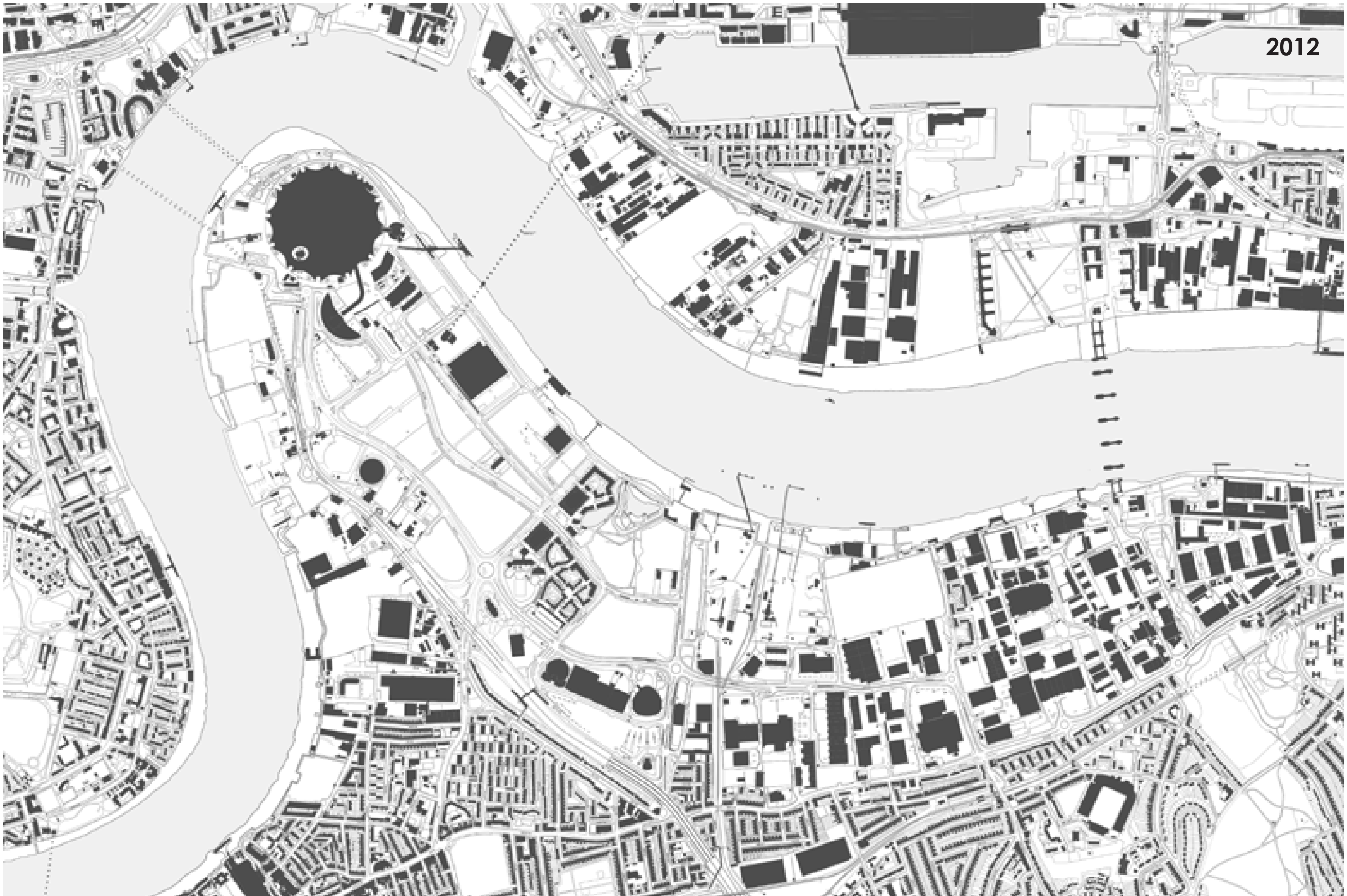


Fig 3.40 2012 OS Map of Greenwich Peninsula

The Dome, or O_2, proved to be a very successful venue for the 2012 London Olympics, hosting gymnastics and basketball. A cable car linking Royal Victoria Dock and the Greenwich Peninsula was constructed ready for the Olympics. This cable car, designed by Wilkinson Eyre, was named the Emirates Air Line after its principal sponsor. In honour of Queen Elizabeth II's Diamond Jubilee, the local authority was renamed the Royal Borough of Greenwich in 2012, during which it hosted three Olympic venues.

A retail shed at 30 Bugsby's Way, built in the 1980s and occupied by Matalan, was demolished in 2014. This steel-framed shed released both steel and aluminium for recycling, including a polyester powder-coated shop front (red), which ran the length of the store along Bugsby's Way. A terrace of three retail stores totalling 4,645m^2 is proposed for this site. It is due to be built in 2015; however, the site is currently hoarded and vacant. The neighbouring Brocklebank Industrial Estate to the east on Bugsby's Way is also under threat of demolition for further retail development, although many sheds also from the1980s are already retail or wholesale outlets.

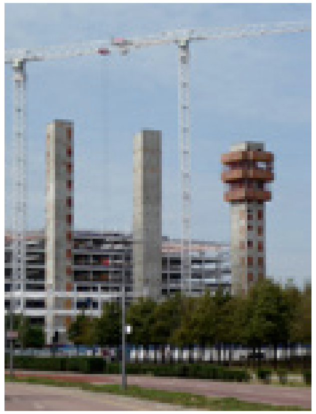


Fig 3.41 Construction of office buildings during 2008, designed by Terry Farrell & Partners

Fig 3.42 Greenwich Peninsula aerial view, late 2011

Fig 3.43 Looking toward Peninsula Square showing the Dome, Ravensbourne College, and office buildings designed by Terry Farrell & Partners

Fig 3.44 Emirates Airline cable car, designed by Wilkinson Eyre, built for the 2012 London Olympics

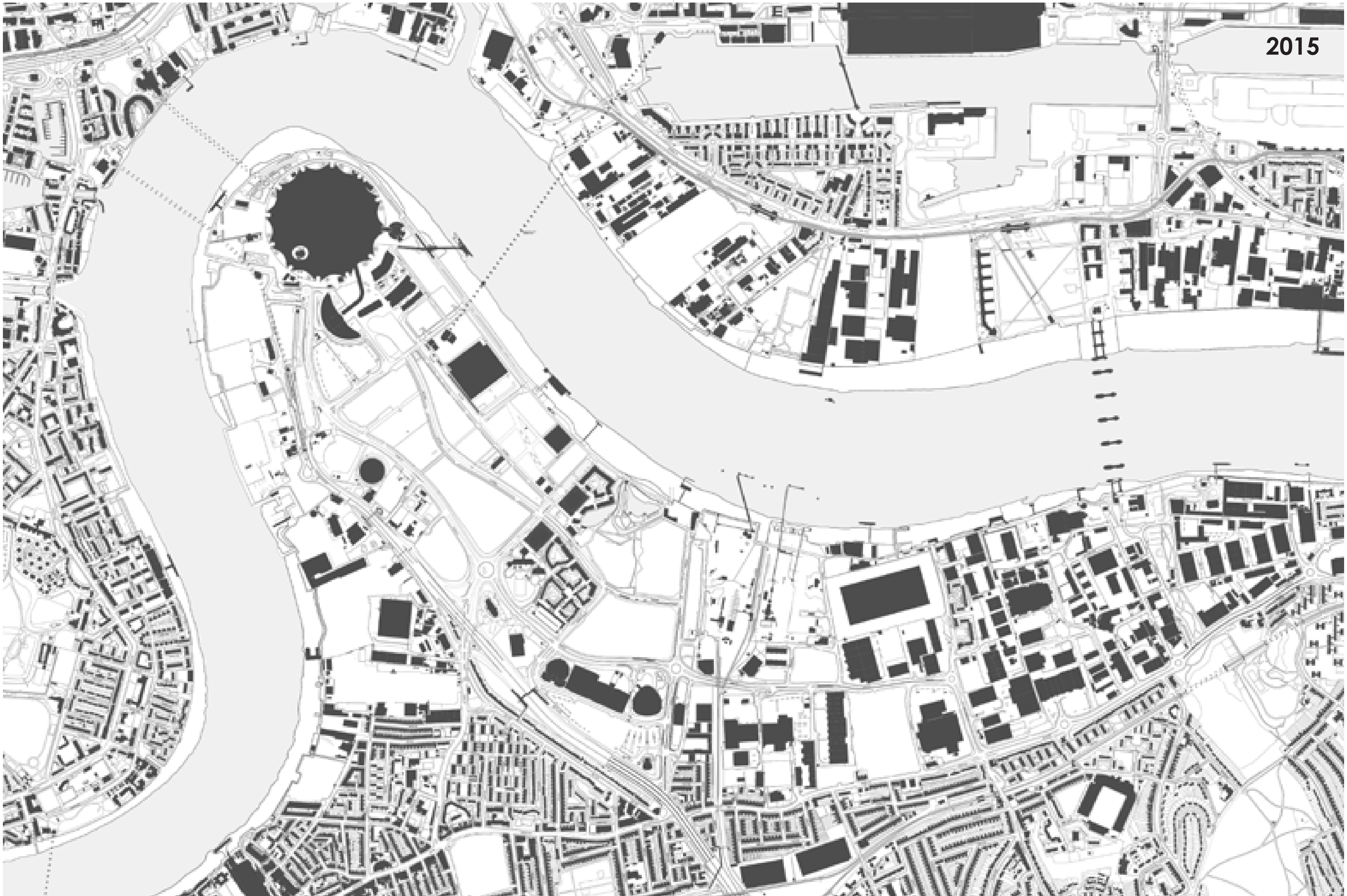


Fig 3.45 Early 2015 OS Map of Greenwich Peninsula

On the south side of this street, new Sainsbury's and Marks & Spencer stores are under construction and are due to be completed during 2015. Sainsbury's appear to be building a larger supermarket in an era when their profits are growing via small neighbourhood express stores. Have they invested in the wrong future or will the future population growth in the area prove this move to be successful? The two-storey Marks & Spencer store will provide 13,000m^2 of retail. The new Sainsbury's supermarket on the same site but facing Bugsby's Way will be 7,430m^2, almost 50 per cent larger than the Chetwoods' award-winning supermarket, opened in 1999, which Sainsbury's will be vacating. Warehouses from the 1960s and 1970s on this site were demolished in 2013 to enable the construction of these two new retail outlets. These earlier buildings were not rich in aluminium, being predominantly constructed with steel portal frames and brick skins; however, aluminium shop fronts had been introduced during the 40–50-year life of these sheds, as many were used as warehouse-like retail outlets selling carpets and sofas, for example.

Demolition of the 1999 Sainsbury's supermarket and the former Comet store, currently occupied by Matalan, was granted by the Royal Borough of Greenwich, under an outline planning permission, on 9 December 2014, for a single non-food retail store of 33,000m^2. The applicant was IKEA, who propose to build a new store. The very significant increase in retail area is based on their multi-storey approach to furniture retailing, which they have standardised throughout the world.

In a zone bounding the River Thames that was predominantly industrial up to the 1970s, some world-class industries remain, including Stone Foundries, founded in 1938, on Stone Lake Park, New Charlton, who produce high-quality aluminium castings for the automotive and aerospace sectors – high added-value products based on the local tradition that was started by the Royal Arsenal in Woolwich when it established a foundry there in 1717.

If and when the 1999 Sainsbury's supermarket is demolished, this will release an aluminium standing-seam roof of over 5,000m^2 and the aluminium shop front frame to recycling. Although an award-winning and groundbreaking building will have been lost, the promise that it was built from sustainable materials will have been fulfilled.

Fig 3.46 The Chetwoods' award-winning Sainsbury's Millennium store is set to be demolished together with the former Comet Store in 2015

Fig 3.47 Aluminium standing-seam roof of Sainbury's Millennium store

Fig 3.48 Autosport high-precision lost-wax aluminium casting by Stone Foundries, New Charlton

In late 2014 and early 2015, the Football Soccer Dome, formerly the David Beckham Football Academy, which had served as a training venue for the 2012 Olympics, was disassembled, with the potential of reuse on another site. This land has been earmarked for housing, which is being delivered by Greenwich Peninsula, trade name of Knight Dragon Developments Ltd, a joint venture by Quintain and Knight Dragon. The first phase of this development will deliver 704 homes on the peninsula by the end of 2015, with planning permission having been secured for a further 882 homes in 2014. The total number of new homes planned to be built here is 10,000, of which about 38 per cent are intended to be affordable homes. Alongside this, a further 350,000m^2 of office buildings is also proposed. The scale of this development has prompted Knight Dragon Developments Ltd to commission a pavilion, which is used for marketing, and a discrete public restaurant. Designed by Marks Barfield, architects of the London Eye, these Gateway Pavilions opened on Peninsula Square opposite the Dome in 2014. Also under construction in 2014 were two hotels, both close to Blackwall Point: a 452-bedroom Hilton Hotel and an 18-storey, 453-bedroom InterContinental Hotel. These are due to open in 2015.

Fig 3.49 New Sainsbury's under construction off Bugsby's Way, early 2015

Fig 3.50 Pavilion and restaurant by architect Marks Barfield on Peninsula Square, completed in 2014

Fig 3.51 The Football Soccer Dome being disassembled, early 2015

Fig 3.52 2015 view of Greenwich Peninsula with two Hotels under construction next to the Dome

Fig 3.53 Aerial view of Peninsula Square with Canary Wharf and London beyond

Fig 3.54 Millennium Village by Ralph Erskine and EPR Architects, completed in 2000

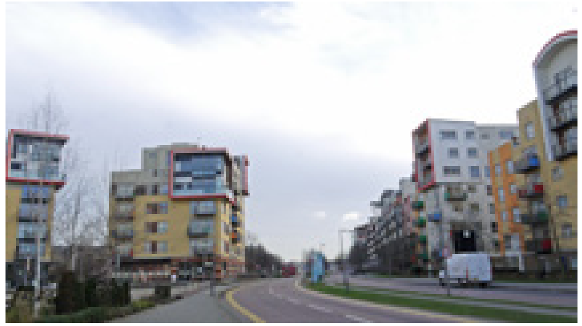
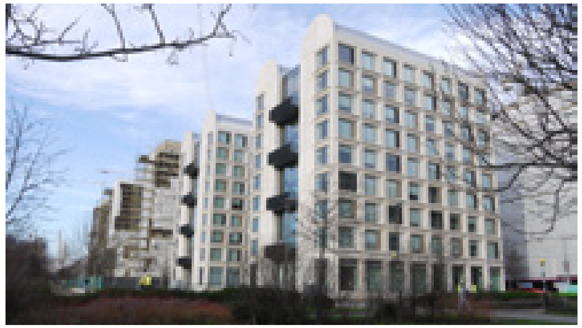


Fig 3.55 Three-storey housing with related apartment towers on Olympian Way by developers Bellway, completed in 2011

Fig 3.56 Parkside Apartments by Knight Dragon Developments Ltd, to be completed by the end of 2015

Fig 3.57 West Parkside Apartments, designed by C.F. Moller and Jestico + Whiles for Knight Dragon Developments Ltd, completed in 2014



Greenwich Millennium Village is also being extended, with the design led by Jestico + Whiles. It would appear that the shortage of housing in the UK, and in London in particular, combined with rising house prices is resulting in the delivery of a significant volume of housing on Greenwich Peninsula, almost 20 years after its regeneration commenced. Aluminium is the first-choice material for windows and curtain walling throughout recent projects on the peninsula, combined with the extensive but not exclusive use of aluminium cladding.

In February 2015, Allies & Morrison submitted an outline planning application for further large-scale primarily residential development on Greenwich Peninsula on behalf of Knight Dragon Developments Ltd, including a further 2,000 new homes.[14] As part of this master plan, the capacity of the North Greenwich Transport Interchange to handle both the present and future residential population of the peninsula and the events at the Dome is being questioned. Thus Foster + Partners' interchange, with its 6,500m^2 aluminium standing-seam roof and extruded aluminium ceiling, may be demolished in the next ten years, having lasted less than 25 years. If it is demolished, this would release aluminium into the recycling flow.

Over the past 25 years, this zone of change within London has seen the demolition of the gasworks and diverse industrial buildings including Tunnel Refineries. This has led to regeneration, albeit slowly, with a net flow of metals to recycling – an example of urban mining. Many of the structures will have been steel; however, based on the TU Delft study (see p. 35), a significant quantity of aluminium will have been recycled and some industrial processes may have used equipment rich in aluminium.[15] In this zone of change, aluminium has clearly played its part as a servant of sustainability.

Fig 3.58 Gasometer, Greenwich Peninsula, photographed early 2015

Notes

1 United Nations Population Fund, *Urbanization*, available online at www.unfpa.org/pds/urbanization.htm (accessed June 2012).
2 Greenwich Marshes were drained in the seventeenth century by Dutch engineers to create farming land.
3 M. Mills (1999), *Greenwich Marsh: The 300 Years Before the Dome*, M. Wright, London.
4 J. T. Howard Turner (1977), *The London Brighton and South Coast Railway: 1. Origins and Formation*, Batsford, London, pp. 40–44.
5 Ibid.
6 N. Crafts (1997), *Britain's Relative Economic Decline 1870–1995*, Social Market Foundation, London.
7 House of Commons Library (2014), *Manufacturing: Statistics and Policy*, House of Commons Library, London, 13 November, p. 4, available online at *www.parliament.uk/briefing-papers/sn01942.pdf (accessed April 2015).*
8 National Gas Museum, *Gas Industry Timeline*, available online at http://nationalgasmuseum.org.uk/gas-industry-chronology/ (accessed January 2015).
9 R. Dunlop (2013), *Sainsbury's, Bugsby's Way, Greenwich Peninsula*, The Rubble Club, 29 November, available online at www.therubbleclub.com/2013/11/sainsbury's-bugsby's-way-greenwich-peninsula/ (accessed January 2015).
10 Ibid.
11 Chetwoods Architects, *Sainsbury's Millennium Store, Greenwich*, available online at http://chetwoods.com/portfolio/sainsburys-millennium-eco-store-greenwich/ (accessed January 2015).
12 Rogers Stirk Harbour + Partners LLP, *Millennium Experience*, available online at www.rshp.com/work/all_projects/millennium_experience (accessed January 2015).
13 R. Kronenburg (2012), *Live Architecture: Venues, Stages and Arenas for Popular Music*, Routledge, London.
14 Information obtained from Knight Dragon Developments Ltd during the Greenwich Peninsula development public consultation, January 2015.
15 The aluminium used within industrial processes as a source for recycling merits further research, as it was not a part of the scope of the TU Delft study (2004).

FOUR

short-life architecture: selected typologies

Short-Life Architecture: Selected Typologies

Although architecture is typically associated with long life expectancy, as revealed in the first report in the Towards Sustainable Cities Research Programme, *Aluminium and Durability*[1], there are some architectural typologies that typically have shorter life expectancies, for programmatic reasons. The short-life architectural typologies selected for consideration in this chapter are:

- post-disaster housing;
- pavilion and exhibition architecture.

All of the short-life architecture case studies within this chapter incorporate a significant use of aluminium. Not all of the examples led directly to demolition and recycling.

Fig 4.1 Aerial photograph of London South Bank showing the Festival of Britain

Post-Disaster Housing

The UN's Refugee Agency has estimated that '3.5 million people live in refugee tents worldwide'.[2] It is thought that people can often live in these tents for '12 years'.[3] Unpredicted disasters require immediate, dependable aid at short notice with limited construction tools. It has also been calculated that although these structures are classed as 'temporary' (lasting for only a limited period of time; not permanent), the solution must be structural, durable, dependable and versatile. Aluminium structures have become popular within this field as they fulfil this list of requirements, with the additional benefit of complete recyclability.

Aluminium structures offer the following qualities:

- **Durability** – Aluminium is strong, rust-proof and able to handle extreme weather conditions. It is also lightweight, at around one-third of the weight of steel, and long lasting.[4]
- **Reuseability and ease of disassembly** – Reversible connections allow for great versatility. The Design for Disassembly [DfD] methods of reversible jointing permit reuse and simple relocation. These structures are often prefabricated, which creates an opportunity for space efficiency, often a critical limiting factor in disaster relief zones with high population densities, such as refugee camps. As a result of a prefabrication method, fast on-site construction is possible.
- **Recyclability** – Aluminium frames can easily be separated and achieve near 100 per cent recyclability.

Post-Disaster Housing in Europe

During the Second World War, thousands of people in Britain and Europe were made homeless and forced to live in makeshift shelters or in crowded family housing. To solve the need for housing in Britain, the Prime Minister Winston Churchill promised 500,000 temporary new homes under the Temporary Housing Programme sponsored by the Ministry of Works. The first prototypes were displayed in 1944 outside the Tate Gallery in London. As steel was in short supply due to high volumes being used for the war effort, this led to the design of prototypes constructed from various alternative materials, including aluminium.

The Aircraft Industries Research Organisation on Housing [AIROH] House

The aluminium prefabricated house was the most representative of the ideal of a factory-produced house.[5] Acting on an invitation by aircraft component manufacturer Morrisons Engineering for a strategy of industrial development that could be implemented following perceived post-war decline in demand for aluminium

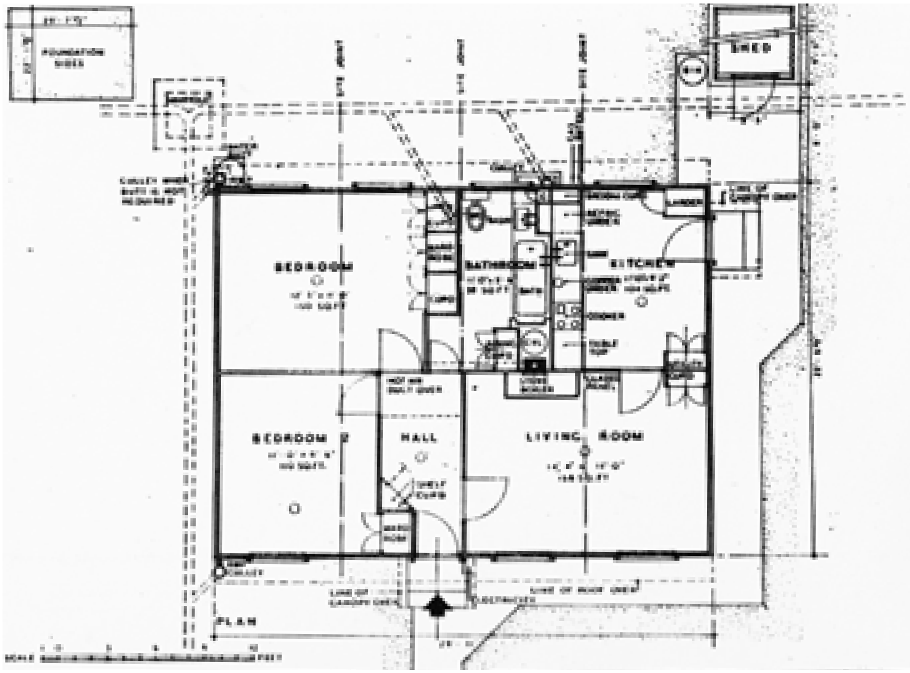


Fig 4.2 Plan of AIROH aluminium house showing division into four prefabricated segments

Fig 4.3 Aluminium plane production at the Blackburn Aircraft factory during the Second World War

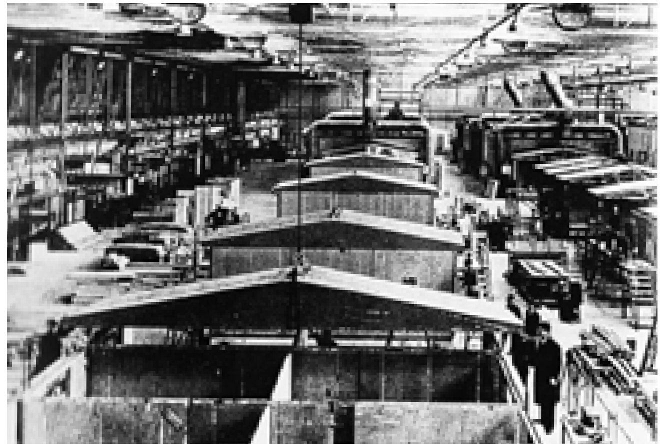


Fig 4.4 Factory production of AIROH aluminium homes in prefabricated segments

Fig 4.5 AIROH prefabricated aluminium house, St Fagans, Cardiff, South Wales, photographed 2012

aircraft,[6] the Aircraft Industries Research Organisation on Housing [AIROH] was incorporated in 1942, made up of 13 British aircraft firms.

The AIROH designed an all-aluminium, two-bedroom house as part of a 1944 government initiative to address an anticipated housing shortage. The AIROH made use of the spare capacity within the aircraft industry by using production lines that once produced Spitfires to manufacture prefabricated aluminium housing at a rate of one house every 12 minutes.[7]

The production of the aluminium bungalow had wider implications than simply as a solution to the post-war housing crisis; it was also important for the aircraft industry and for Britain as a whole as a means of preventing mass unemployment. The Minister of Aircraft Production at the time, R. S. Cripps, recognised the aluminium industry as a sector that could supersede the coal and cotton industries.[8]

The AIROH housing was initially described as temporary for mainly social and political reasons. The public were perceived as reluctant to live in small two-bedroom houses, with unconventional production methods and aesthetics. There was also a need to prevent conflict between central and local governments regarding housing provisions and to emphasise the post-war return to traditional building methods. However, the prefabricated houses outlasted their design life as well as becoming popular with tenants.[9] Under Scottish Building Regulations, the life expectancy of an AIROH prefab was rated as 60 years.[10]

The production of the AIROH prefabs cost £1,610, which at the time was more than a traditional house cost. The quality of the design and production meant that the houses lasted long

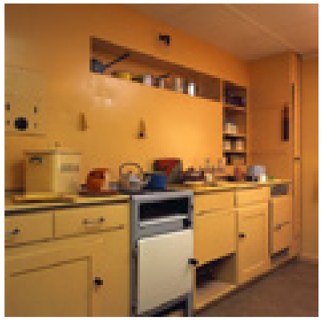
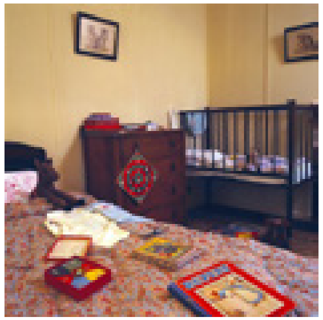




Fig 4.6–Fig 4.8 Internal views of AIROH aluminium bungalow at St Fagans

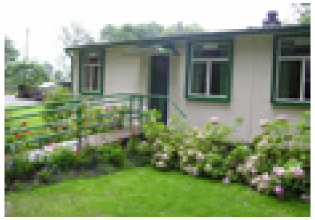
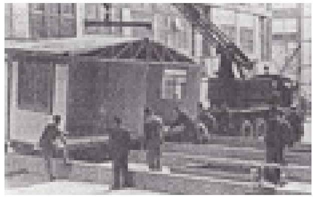




Fig 4.9 [top left] AIROH prefabricated aluminium home at St Fagans

Fig 4.10 [bottom left] End bedroom segment of an AIROH aluminium home being craned into position on brick footings, 1945

Fig 4.11 [right] AIROH prefabricated aluminium home, still in use in Redditch, England

after the 10–15-year design life. The aluminium prefabricated houses were manufactured in five factories: Bristol Aeroplane Co. in Weston-super-Mare; Vickers-Armstrong in Blackpool and Chester; Blackburn Aircraft in Dumbarton; and A. W. Hawksley in Gloucester.[11]

The AIROH house was designed in such a way that it was fabricated in four sections, 2.29m (7' 6") in width and 6.87m (22' 6") in length, in the factory, transported to the site by lorry and then connected in position, taking approximately 30 to 40 man-hours.[12]

The four-module principle affected the spatial layout of the house; in order for the module system to work, the toilet was situated in the bathroom, whereas in other prefabricated houses, the toilet was separate, therefore no plumbing connections were required on site. The house was constructed out of extruded aluminium sections forming the frames of the floor, wall and roof trusses, with external aluminium sheets riveted to the aluminium frame performing as cladding. The roof was finished with 61 x 15cm (2' x 6") wide aluminium sheet made with an inner corrugated sheet finished with a bitumen layer and faced externally with 20g aluminium sheet.[13] '188 tons of aluminium was used per house, 82% of which was recycled scrap.'[14] This early use of aluminium was unprecedented at the time in Britain.

Rapidly Deployable Structures

A Rapidly Deployable Structure is a temporary structure that can be quickly deployed in emergency situations. These structures can be little more than tents or hard-walled buildings that break down into small components. The shelters are pre-engineered in a wide range of sizes, many using lightweight aluminium frames, with a fabric tension structure providing enclosure. The most frequent uses of Rapidly Deployable Structures are as:

- aircraft hangers and vehicle storage structures;
- ammunition storage structures and warehouses;
- post-disaster relief structures;
- emergency shelters and temporary housing;
- environmental remediation structures;
- maintenance buildings;
- mess halls;
- mobile surgical hospitals.

The functional requirements of Rapidly Deployable Structures for the military are:

- ease of transportation, with overall dimensions that do not exceed the capacity of existing trailers;
- a system set-up time of 30 minutes or less;
- provision of environmental controls that will protect computing systems from extremes of temperature and humidity;
- compatibility with existing camouflaging techniques.[15]

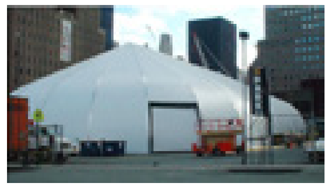
Fig 4.12 Tents used as temporary accommodation by the military

Fig 4.13 [left] Nanshan refugee camp in China

Fig 4.14 The UN provided tents for refugees living in the Jordanian desert, typically tented structures are used in post-disaster areas

Fig 4.15 [far right] IKEA flat-pack refugee shelter

Fig 4.16 The IKEA flat-pack refugee shelters being tested in Ethiopia



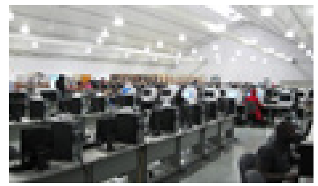


Fig 4.17–Fig 4.20 Sprung-tensioned membrane fabric structures, which have a lightweight aluminium frame and perform well in all climates, from the 'Ground Zero' construction site to the Arctic Watch Wilderness Lodge

Pavilions and Exhibition Architecture

Pavilions and exhibition architecture are very important to the history and development of the discipline and the built environment. They are very public, highly visited and the closest our industry has to an experimental architecture. Pavilions and exhibition architecture have to be professionally delivered, often on tight design and assembly schedules, with full consideration of health and safety for the assemblers, the staff and the general public. Pavilions and exhibition architecture are a test bed for ideas and new (or newer) technologies and techniques, which often cross over into mainstream contemporary architecture and infrastructure in a very short timescale.

The following case studies display the use of aluminium in pavilion and exhibition architecture:

- Dome of Discovery: Architect Ralph Tubbs, 1951;
- Skylon: Architect Powell & Moya, 1951;
- Aluminium Centenary Pavilion: Jean Prouvé, 1954;
- IBM Travelling Pavilion: Architect Renzo Piano, 1984;
- Cellophane House™: Architect KieranTimberlake, 2008;
- Serpentine Gallery Pavilion: Architect SANAA, 2009;
- UK Pavilion for Expo 2010: Heatherwick Studio, 2010.

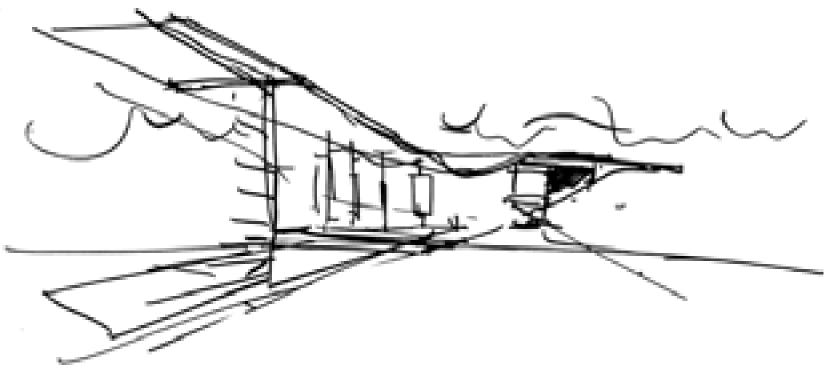
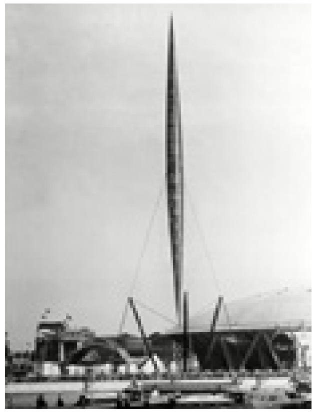


Fig 4.21 Sketch of the First Nations Garden Pavilion, Montreal, by Saucier + Perrotte

Dome of Discovery: Architect Ralph Tubbs and Skylon: Architect Powell & Moya, at the Festival of Britain in 1951

Fig 4.22 The Skylon by architect Powell & Moya at the Festival of Britain was clad in aluminium

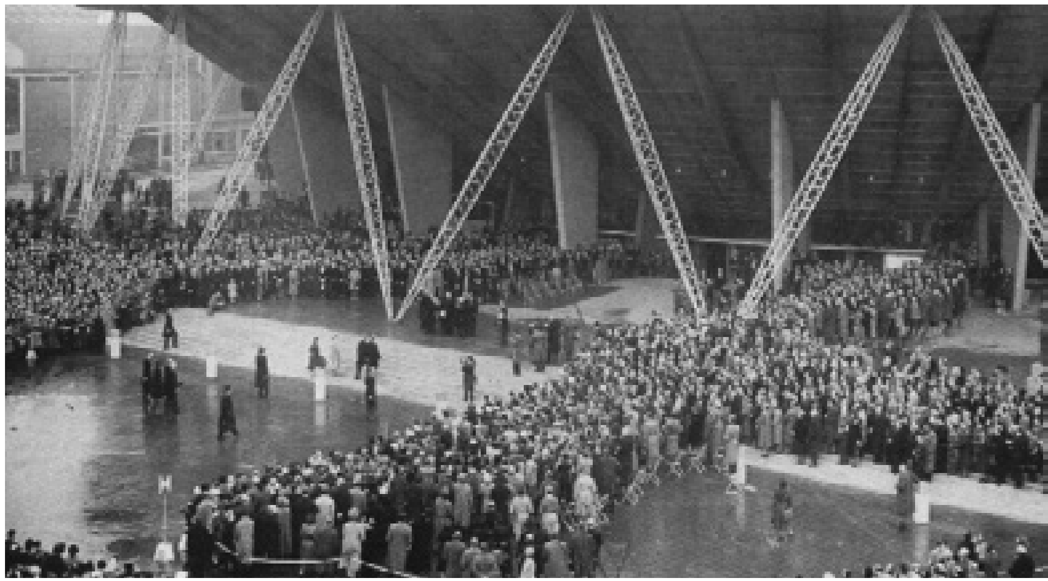
Fig 4.23 [bottom] Crowds queing to enter the Dome of Discovery during the Festival of Britain on London's South Bank



The Dome of Discovery was built as a temporary exhibition space for the Festival of Britain celebrations held on London's South Bank in 1951. Designed by Ralph Tubbs with consulting engineers Freeman Fox & Partners, the Modernist dome quickly became an iconic structure helping to popularise modern design in Britain.

The dome was constructed out of concrete and aluminium. Aluminium was used for structural members and for the cladding of the dome; this was due to steel being in short supply following the Second World War, and also 'for its lightness [and] because it captured the spirit of the postwar years'.[16] The dome exemplified the British enthusiasm for inventiveness and experimentation by having a diameter of 111m (365') and a height of 28m (93'), making it at the time the largest in the world, and by using the latest technology and building materials available.

The extruded aluminium structure was designed in a systematic way, reducing the number of parts and ensuring they could be prefabricated. These were connected to two brass pins that defined the geometry of the dome. The external aluminium trusses were both a structural and an aesthetic solution; the external aluminium structure provided resistance to the dome's outward forces, whilst creating sheltered external space, and aesthetically creating an ever-changing vista for the visitor walking around the perimeter.



Controversially, following the popular Festival of Britain, the new Conservative government (elected in October 1951) demolished the dome and sold it as scrap to George Cohen, Sons & Company of London. In an attempt to save the dome, Tubbs and Freeman Fox costed the relocation of the dome to the former site of Crystal Palace, which amounted to £55,000 – but this never materialised.[17]

The Skylon, designed by Powell & Moya, was constructed as part of the Festival of Britain along with the Dome of Discovery; this was also clad in aluminium. On its deconstruction, this too was sold to George Cohen, Sons & Company and was combined with the scrap aluminium from the Dome of Discovery. Fragments of this aluminium cladding were repurposed into commemorative knives.[18] The aluminium that was recycled would have amounted to a large proportion of the aluminium scrap available in Britain in 1952.

Fig 4.24 [bottom left] Aerial photograph of London's South Bank showing the Festival of Britain

Fig 4.25 [top right] The Dome of Discovery by architect Ralph Tubbs and Freeman Fox & Partners

Fig 4.26 [bottom right] Night view of The Skylon and the Dome of Discovery

Aluminium Centenary Pavilion: Jean Prouvé, 1954

Jean Prouvé's Aluminium Centenary Pavilion was built in 1954 to celebrate the 100th anniversary of the industrial production of aluminium in France. L'Aluminium Français commissioned the pavilion to host an exhibition that would demonstrate the possibilities of aluminium in construction and promote its further use. Prouvé did this by combining different manufacturing techniques for constructing with aluminium, such as folded sheet, extrusions and castings, alongside using different types of aluminium itself; it was only the façade panels that were made from almost pure aluminium. Prouvé is known for his ability to intelligently connect a material's capability to a construction logic, an aesthetic born through making.[19] Much of his career was dedicated to designing lightweight building systems, which 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. Over 60 years since its initial conception, the pavilion's structural use of aluminium is still an exemplar of how it can replace steel and timber.

Fig 4.27 Inside the exhibition where contractors and manufacturers displayed boards about their products

Fig 4.28 Assembled beams on site in Paris

Fig 4.29 Advertisement for the Exhibition of Aluminium in Jean Prouvé's Aluminium Centenary Pavilion from 12 June to 21 July 1954

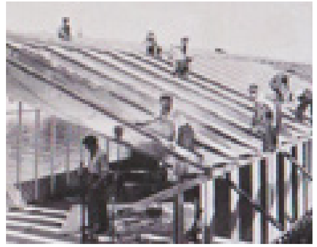


Fig 4.30 Construction of the pavilion in Paris

Fig 4.31 Aluminium panels being attached to the pavilion structure in Paris

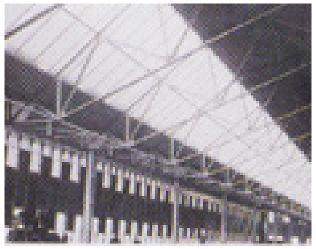
The pavilion was designed and manufactured to be a 152m long structure with a frame spanning 15m, placed at 1.34m centres. The pavilion was assembled beside the River Seine in central Paris in 21 days, using prefabricated components that Prouvé designed to be as easily demountable as mountable. The structure's subsequent journey displays this flexibility for reuse rather than recycling.

The pavilion remained in Paris until early 1956, when André Lannoy Sr and André Lannoy Jr purchased it from the demolition contractors as they thought it deserved a better fate than being used for scrap metal. It was then transported to Lille and rebuilt on the Foire Internationale site, where it provided a much-needed extension to the existing exhibition hall, the Palais de la Foire, for which Prouvé designed and manufactured the façade.

Fig 4.32 View of the illuminated Aluminium Centenary Pavilion in front of the Eiffel Tower on the banks of the River Seine in Paris

The Aluminium Centenary Pavilion endured drastic transformation when rebuilt in Lille, leaving it almost unrecognisable from its first appearance in Paris. The pavilion in Lille had two naves in an L-shaped plan with a steel structure completing it into a rectangular hall. The folded-aluminium roof beam components were cut and mitred to form the L-shape and were supported on a steel truss. Prouvé's aluminium frames were assembled without the smaller extrusion posts and instead the rear façade castings sat on a steel beam. The rear façade extrusions were therefore not needed and were instead used to extend the front façade extrusions and make the overall building taller; to do this, each of the smaller extrusions were cut into three pieces and welded to the larger extrusions.

The building was made even more anonymous by beige- and orange-painted timber cladding, which meant that all that was visible of the original Prouvé structure was the cornice. The



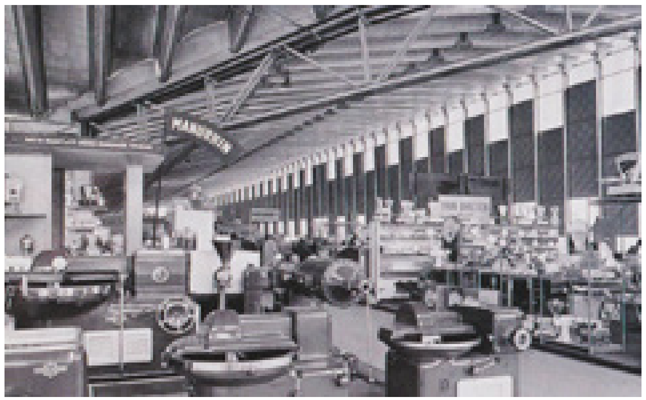


Fig 4.33 [top left] The mitred roof panels in Lille, 1956

Fig 4.34 [above] The steel structure connecting to the aluminium pavilion, used in Lille only, 1956

Fig 4.35 [left] The mitred beams with supporting steel truss

Fig 4.36–Fig 4.39 The Aluminium Centenary Pavilion during dismantling in Lille

front façade castings and extrusions were also painted yellow for decorative purposes – 'pour faire jolie'. Although these alterations were not sympathetic to the pavilion as designed by Prouvé, they showed the inherent flexibility of both aluminium as a material and the system of components he designed.

In 1987, Peter Sulzer, author of *Jean Prouvé: Complete Works*, visited the exhibition site when the façade of the Palais de la Foire was being demolished and the Foire authorities did not know the Aluminium Centenary Pavilion was nearby: 'a masterpiece forgotten!'[20] The pavilion was scheduled for demolition in 1990, but it was its inclusion in the *Supplementary Inventory of Historical Monuments* in February 1993 that saved it from irremediable destruction.[21] It was in these circumstances that André Lannoy Jr agreed to ensure the dismantling and storage. The process of disassembly in July and August 1993 was akin to an archaeological dig, where each piece was released and recorded. From September 1993 to October 1998, the pavilion's components were stacked on a rented plot of land in Marquette-lez-Lille at a cost of 7,000 francs per month, whilst Lannoy searched for reassembly options.[22]

In 1997, an exhibition entitled *L'art de l'ingénieur* at the Centre Georges Pompidou in Paris exhibited three bays of the Aluminium Centenary Pavilion and helped to raise its profile.

Fig 4.40 The disassembled Aluminium Centenary Pavilion frames being stored at Marquette-lez-Lille

Fig 4.41 Aluminium components in storage, 1997

Fig 4.42 Adjustable footing detail

Fig. 4.43 The cast beams on site in Villepinte, which had been painted in Lille

Fig. 4.44 The aluminium extrusions from the original pavilion in Paris had been cut and welded to alter the height of the pavilion in Lille

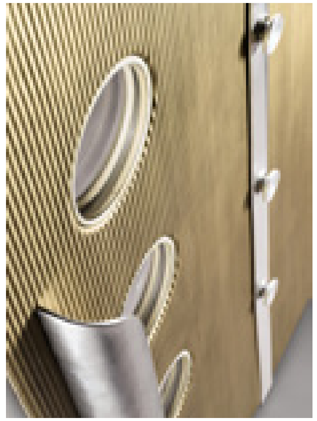


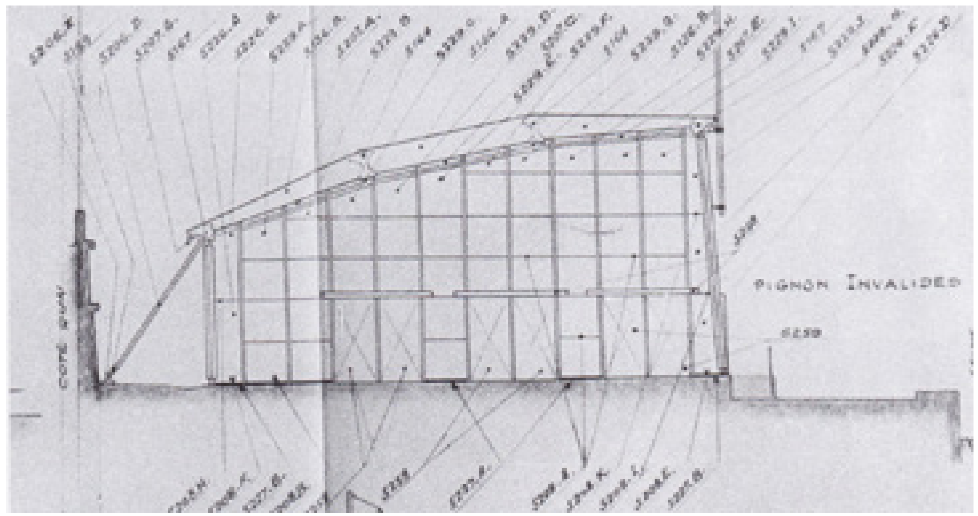
Fig 4.45 Picture used to advertise the restored Prouvé door sold at auction

In 1998, the pavilion was bought by SIPAC, the owner of its current location at Villepinte, near Charles de Gaulle Airport, a large exhibition site with eight halls. This relocation suffered some initial legal difficulties, as the Villepinte exhibition centre did not want the protective perimeter that came with the pavilion's listed status. At that time, the only method to reduce a listed building's perimeter was to replace it with a new well-reasoned perimeter determined by a heritage study. The administration therefore conducted such a study in 2000, which removed the building's protective perimeter. Thus, the conservation of the Aluminium Centenary Pavilion pushed the legal boundaries of French administrative protection, leading to debates over whether the existing heritage system was obsolete and whether it could adapt to component-based architectural works of the future.[23]

The heritage study of the pavilion was challenged in 2010, when it was revealed that the original pavilion doors and one cladding panel were to be sold at auction.[24] The failure of the cultural heritage officials to list these in the inventory issued with the listing meant that no legal action could be taken to retrieve them. This is a textbook case in the issues that surround listed architecture with dismountable and intentionally transportable pieces, which can adapt according to site-specific, programmatic and spatial needs.

Fig 4.46 Short section of the Aluminium Centenary Pavilion in its first location, Paris

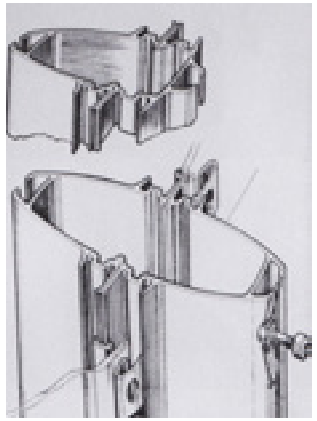
Architecture-Studio [AS], with consultants Richard Klein and Axel Vénacque, carried out the reconstruction and restoration of the



pavilion between 1999 and 2000. The main aim was to return the stored aluminium components to the former glory of the Aluminium Centenary Pavilion when it stood on the banks of the River Seine in 1954; this was achieved using the many drawings by Prouvé. The reconstruction cost €640,000 and the pavilion had to be shortened to 90m, partly due to the parts available after its reconfiguration and partly because it was poorly maintained in Lille. In Villepinte, a total of 68 frames were used, meaning 48 frames were lost or too badly damaged to be reused; this reduced the overall area from 2,250m² to 1,350m².

The folded-aluminium beams were originally made in the Prouvé Workshops from 4 mm semi-hard AG-3 sheet aluminium.[25] Each beam was made in three parts, making the reuse of parts more

Fig 4.47– Fig 4.51 The beams being restored, ready for reassembly in Villepinte



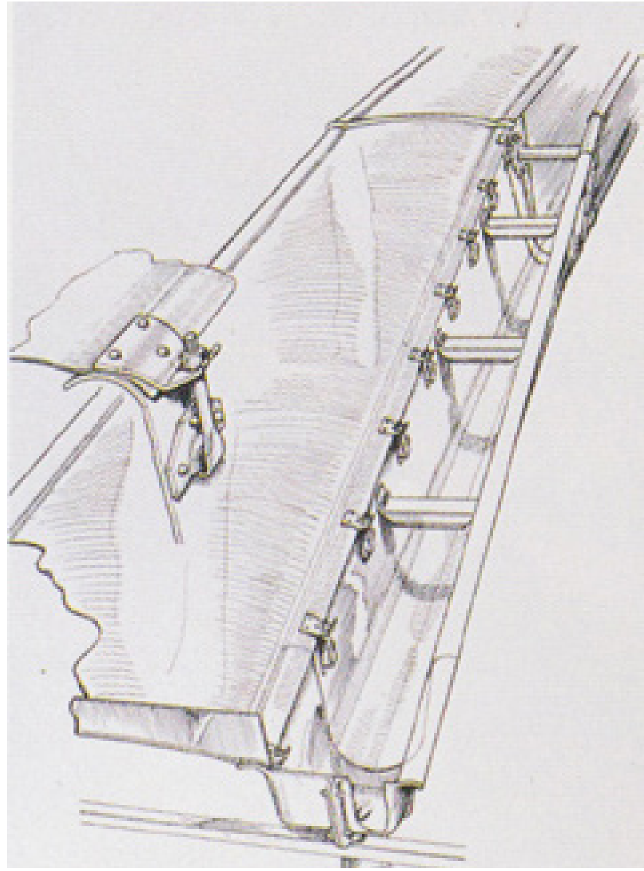


Fig 4.52 [top left] Connecting beams and roof panels during reassembly at Villepinte

Fig 4.53 [bottom left] Drawing by Prouvé of aluminium extrusion, for the aluminium walls

Fig 4.54 [right] Drawing by Prouvé of connection between roof panels and beams

efficient for reconstruction, especially as some of the beams were cut in Lille to build the L-shaped plan. It was not possible to use the cut sections in the reconstruction, but all of the uncut pieces were used for the rebuilding in Villepinte, apart from one-and-a-half beams, which were badly damaged before dismounting.[26]

The roof tiles, which connect to the folded beams using coupling pins, allow for an entirely reversible construction. The 5m long sections are made from thin 1.6 mm aluminium sheet. Some of these were also cut in the Lille reconfiguration, and so a mixture of new and original panels was used in Villepinte.

In Villepinte, the rear elevation extrusions were remade, as these were too badly damaged from the reconfiguration in Lille. The supports on the rear façade were also remade and positioned as they were on the bank of the River Seine. It is actually the use of

Fig 4.55 [left] Front façade in Paris, 1954, with Prouvé-designed aluminium panels

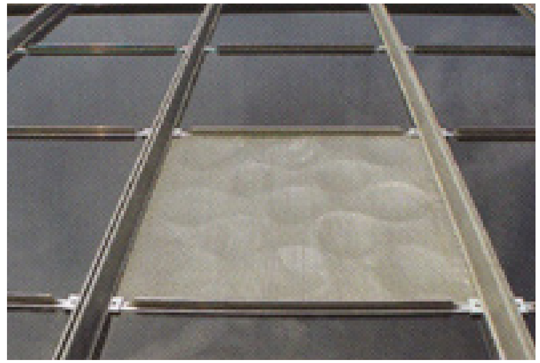
Fig 4.56 [bottom left] Front façade in Villepinte, 2013, with one remaining aluminium panel and glazing

Fig 4.57 [centre right] The only remaining aluminium panel in Villepinte

Fig 4.58 [bottom right] Rear elevation in Villepinte with replaced aluminium panels, extrusions and supports

this independent bracing that allows the pavilion to be adapted to different locations. In Prouvé's original plans for the pavilion, he relied on the wall at the back of the site for structural rigidity.

The main obstacle to the pavilion's difficult journey is that only one of the original Prouvé-designed almost pure aluminium façade panels with calotte-shaped dents remains in Villepinte. Some of these were lost in Lille, due to the L-shaped configuration of the pavilion, in which the rear façade became internal and the panels were not required. The 300 remaining panels from the front façade were all looted from the site at Villepinte. The one remaining panel was set on the front façade as a symbol. It would have cost around €90,000 to make a mould to reproduce these missing panels, which was not possible, and so instead the main façade was fully glazed and the rear façade was clad with new sheet aluminium.



IBM Travelling Pavilion: Architect Renzo Piano, 1984–86

Renzo Piano designed the IBM Travelling Pavilion with the inventive engineer Peter Rice. The pavilion housed an exhibition intended to present the idea of home computing as being a natural part of everyday life. The pavilion has a simple extruded arched form constructed of larch, aluminium and polycarbonate.[27] For more information on the materials of this pavilion, see Chapter Six.

Between 1984 and 1986, the pavilion was erected in 20 cities across 14 European countries, including Paris, Rome, Milan, London, York, Amsterdam and Copenhagen. There were two travelling pavilions, which took about three weeks to assemble on each site, having been delivered by 18 articulated lorries. Peter Buchanan observes that at each location

> a computer simulation was run of outside light and thermal conditions, taking account of the orientation of the pavilion, position of shading trees and so on. This determined the exact placing of opaque pyramidal elements, which were fixed within the transparent ones, and of the mesh screens. Together these controlled glare and heat loads.[28]

Piano's carefully crafted assembly of the components of the IBM Travelling Pavilion formed a construction system, yet in each location a site-specific work of architecture was created.[29]

Fig 4.59 Section and elevations of the IBM Travelling Pavilion by Renzo Piano Building Workshop

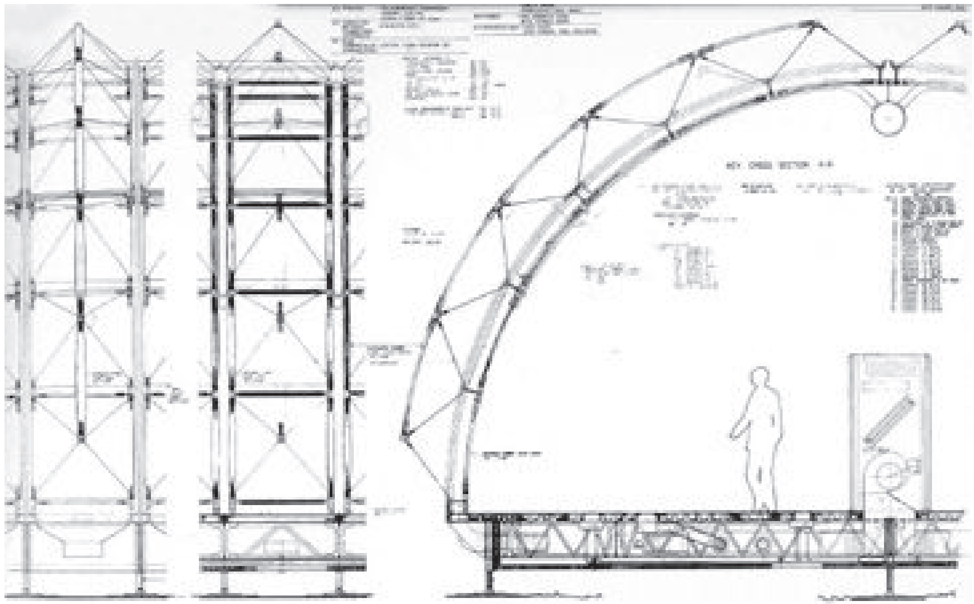
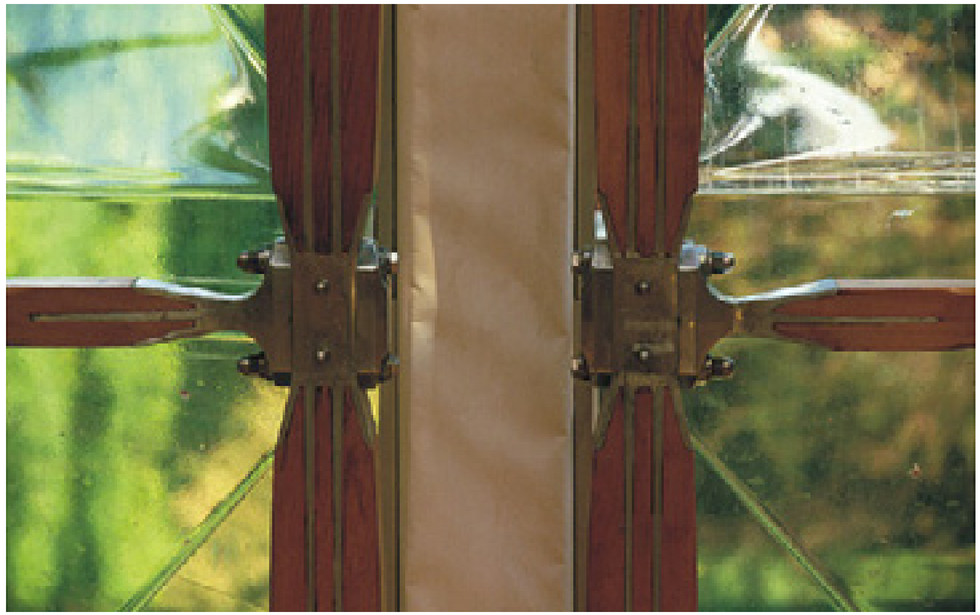


Fig 4.60 The IBM Travelling Pavilion being assembled

Fig 4.61 Flexible polymer movement joint between two timber, aluminium and polycarbonate arches



Cellophane House™: Architect KieranTimberlake, 2008

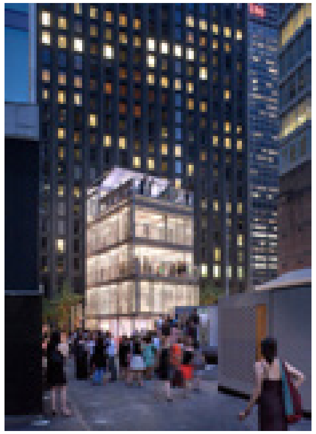


Fig 4.62– Fig 4.63 Day and night views of Cellophane House™ at MoMA, New York, designed by KieranTimberlake

Cellophane House™ is a non-site-specific, adaptable, five-storey town house, commissioned by and shown at the Museum of Modern Art [MoMA] in New York for the 2008 exhibition *Home Delivery: Fabricating the Modern Dwelling*. This project is a progressive development of earlier KieranTimberlake projects: the SmartWrap™ Pavilion with digitally printed integrated skin exhibited at the Cooper-Hewitt National Design Museum in New York during 2004, and the Loblolly House built in Maryland in 2006. All three projects employ an aluminium structural frame and demonstrate the development of the practice's thinking on structure and skins that have been researched and designed parametrically using Building Information Modelling [BIM]. Architects Stephen Kieran and James Timberlake articulated a philosophy to ensure ethical, sustainable and resource efficiency throughout the project's entire life cycle. James Timberlake has described Cellophane House™ as 'not merely a one-off exercise, but a process for discovering new and better ways of fabricating architecture'.[30]

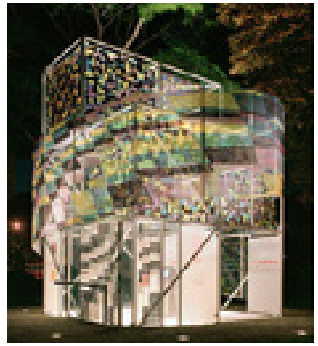
Cellophane House™ was designed for adaptability so that it can respond to a range of climatic factors, solar orientations, slopes and adjacencies, which differ from site to site. The aluminium structural frame for the 167m² (1,800ft²) home was fabricated 'off-site in a factory over the course of thirteen weeks and erected on-site in sixteen days'.[31]

The fixing techniques are entirely reversible and devised from extruded aluminium sections, combined with custom steel connectors. Bosch Rexroth aluminium sections are off-the-shelf components, designed to support industrial manufacturing and aid in the (dis)assembly of the house.[32] This permits homeowners to make seamless alterations to materials and floor plans according to environmental factors and preference throughout the lifetime of the building.

Fig 4.64 [right] Night view of SmartWrap™ Pavilion designed by KieranTimberlake, at Cooper Hewitt, New York

Fig 4.65 [far right] Detail of the extruded aluminium structure and skin of the SmartWrap™ Pavilion

Fig 4.66 [below] The kitchen of Cellophane House™



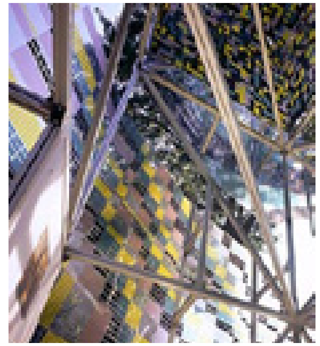


Fig 4.67 [left] Cellophane House™ being assembled in prefabricated chunks

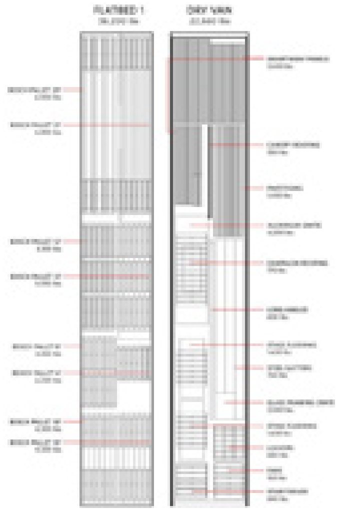


Fig 4.68 Flatbed lorry loading plan

At the end of the exhibition, the house was entirely disassembled and taken into storage, ready for reuse. Several methods of disassembly were calculated and the proposed solution involved disassembling each chunk to evaluate the full potential of design for disassembly and also to minimise storage volume. The modularity of the frame and components allows for efficient transportation. The entire house was packed onto three flatbed trucks and two delivery vans.

The disassembly revealed the need for a system of recording, documenting and tracking the more than 3,000 building components, to ensure reconstruction could take place smoothly. In this instance, each house part was rigorously inventoried and labelled by hand using an ID tag which showed manufacturing information, its position within the structure and its storage location. With the aid of BIM, KieranTimberlake were able to calculate every component required for construction. From this model, embodied energy and recycle mass calculations could be generated. With a complex model such as this, there is the potential to encode all components with this ID tag when initially constructed and to track destination and placement. This can record durability and accessibility and can also facilitate reuse or recycling in the future. Using BIM, there is the potential to create an identification system via direct information transfer at the time of fabrication.

Fig 4.69 Example of a component label

Fig 4.70 All components were labelled by hand

Fig 4.71 [right] Aluminium on flatbed trucks

The initial thesis held through the disassembly process, and virtually no waste was generated. Materials were separated according to physical properties and were sorted with carpentry tools, maintaining integrity for recycling and future use. The recycling and reuse rates were calculated. Once disassembled, it was calculated that 'about 90% of the mass of the house could be recycled'.[33] Embodied energy in building materials can be as high as or higher than the amount of energy a building will consume over its 40-year life cycle, and therefore KieranTimberlake devised the end-of-life planning for Cellophane House™ to incorporate a recovery strategy. KieranTimberlake stated:

> We knew the exact measurements of the house materials, and performed an embodied energy analysis of the Cellophane House™, finding an intensity of 861kWh per square foot. This figure, when compared to current energy intensity benchmarks, reveals that embodied energy is a significant contributor to the lifetime energy profile. The Cellophane House™ disassembly successfully recovered 100% of the energy embodied in materials, demonstrating the potential of this system to significantly reduce carbon emissions by extending the life cycle of materials.[34]

Fig 4.72 Folding glass doors to the terraces of the house provide access and natural ventilation

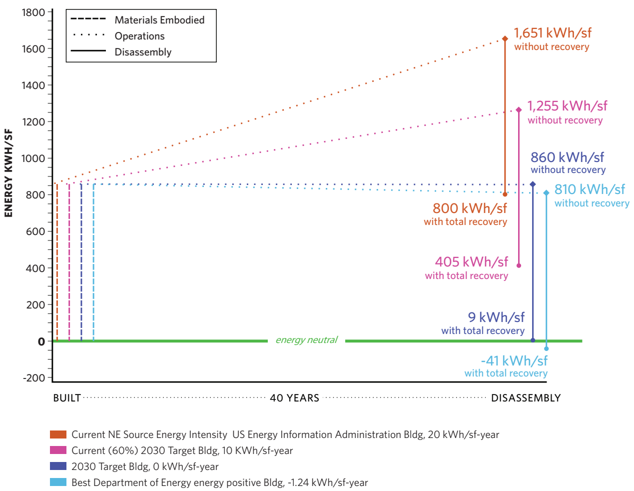
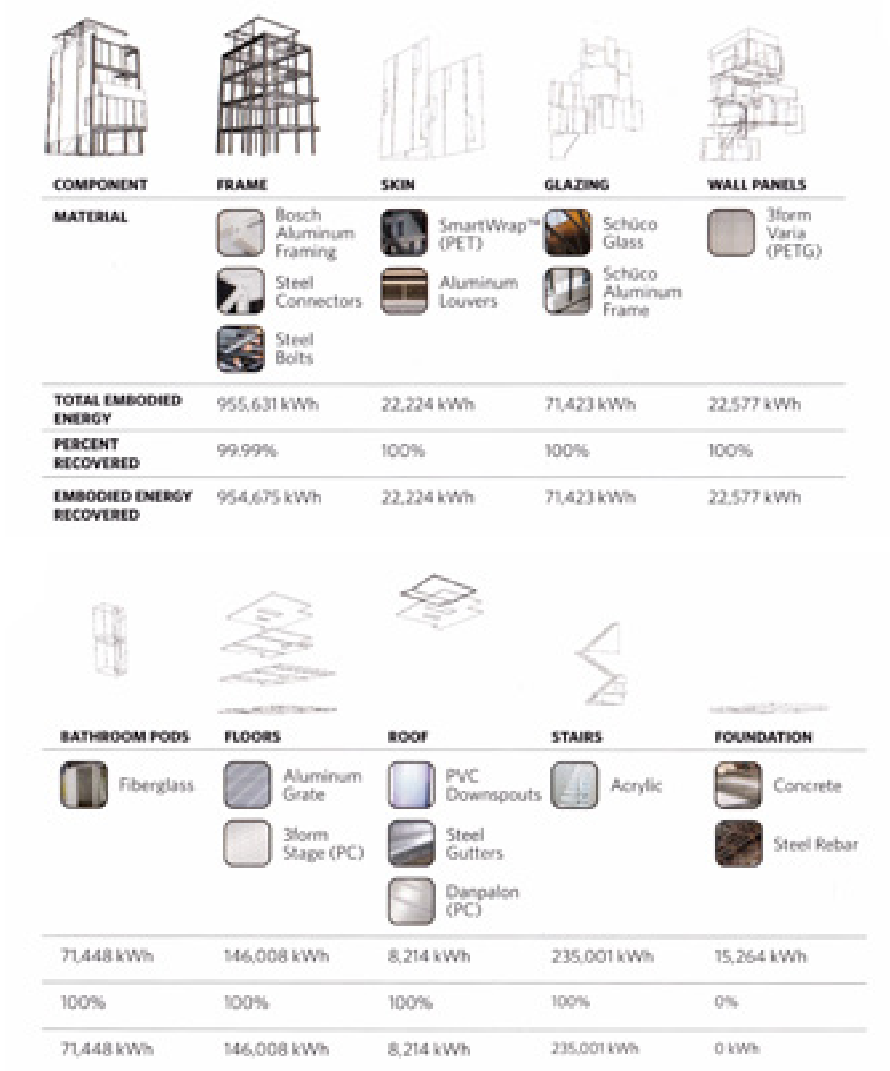
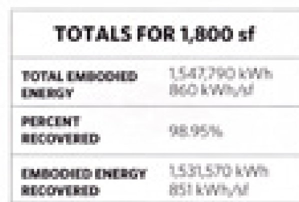


Fig 4.73 KieranTimberlake's comparison of operational and embodied energy of Cellophane House™, highlighting the importance of recovering the embodied energy



COMPONENT	FRAME	SKIN	GLAZING	WALL PANELS
MATERIAL	Bosch Aluminum Framing; Steel Connectors; Steel Bolts	SmartWrap™ (PET); Aluminum Louvers	Schüco Glass; Schüco Aluminum Frame	3form Varia (PETG)
TOTAL EMBODIED ENERGY	955,631 kWh	22,224 kWh	71,423 kWh	22,577 kWh
PERCENT RECOVERED	99.99%	100%	100%	100%
EMBODIED ENERGY RECOVERED	954,675 kWh	22,224 kWh	71,423 kWh	22,577 kWh

BATHROOM PODS	FLOORS	ROOF	STAIRS	FOUNDATION
Fiberglass	Aluminum Grate; 3form Stage (PC)	PVC Downspouts; Steel Gutters; Danpalon (PC)	Acrylic	Concrete; Steel Rebar
71,448 kWh	146,008 kWh	8,214 kWh	235,001 kWh	15,264 kWh
100%	100%	100%	100%	0%
71,448 kWh	146,008 kWh	8,214 kWh	235,001 kWh	0 kWh



TOTALS FOR 1,800 sf	
TOTAL EMBODIED ENERGY	1,547,790 kWh 860 kWh/sf
PERCENT RECOVERED	98.95%
EMBODIED ENERGY RECOVERED	1,531,570 kWh 851 kWh/sf

Fig 4.74 Total embodied energy recovered through disassembly, listed by components and elements

Serpentine Gallery Pavilion: Architect SANAA, 2009

In 2009, SANAA designed the annual temporary Serpentine Gallery Pavilion, in Hyde Park, London, as an ethereal cloud-like structure. It was engineered by Arup and fabricated by Stage One. The challenge set by SANAA derived from a desire for complete absence of connection details. A limited palette of materials and components was chosen to achieve this. The design was an apparently simple floating plan of polished aluminium set within and reflecting the trees and green landscape of Hyde Park. The form of this shimmering roof was also a response to this context, with an organic almost Hans Arp sinuous shape.

SANAA originally intended the roof to be a welded aluminium structure, which may have made it difficult to achieve a consistent silvery polished finish, but this was ultimately rejected as it would have made disassembly and relocation very difficult if not impossible. The design team explored several methods of construction and eventually it was decided that the process of ‘injecting foam into the aluminium wafer would have resulted in too much surface deformation’.[35] In the end, Arup proposed an aluminium and plywood composite, comprising two sheets of 3 mm mirror-polished aluminium, bonded onto 18 mm plywood core. The 560m^2 roof is made up of 172 individual panels, which were CNC fabricated and joined with comb joins in the ply layer. This plane of polished aluminium is supported on 118 high-strength stainless-steel columns; both 40mm and 60mm diameter columns were used and they vary in length from 1.1m to 3.9m. Space within the pavilion is also defined by two curved acrylic walls.

This temporary pavilion is made of durable and long-lasting materials. At the end of the summer of 2009, it was sold to a private buyer, dismantled and reassembled on their land. This almost dematerialised definition of space is possibly one of the most elegant of the Serpentine Gallery Pavilions that have been built each summer since 2000.

Fig 4.75 Serpentine Gallery Pavilion designed by SANAA, 2009

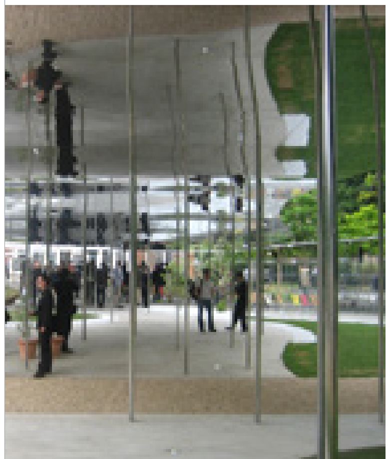
Fig 4.76 [below] Reflection in the polished aluminium as people congregate for an event at the pavilion in Hyde Park

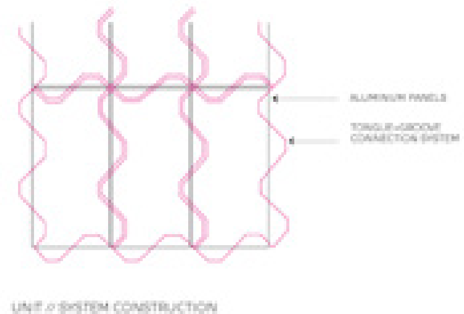
Fig 4.77 [below right] Unit connection system drawing by SANAA and Arup

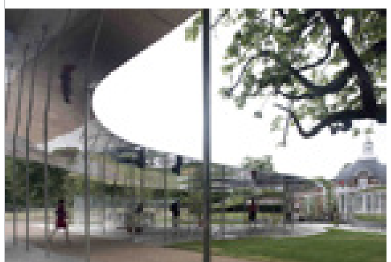
Fig 4.78 [centre left] Curved and polished aluminium underside of the pavilion

Fig 4.79 [bottom left] Aluminium roof of the Serpentine Pavilion 2009

Fig 4.80 [bottom right] Approaching the pavilion in Hyde Park







UK Pavilion for Expo 2010: Heatherwick Studio, 2010

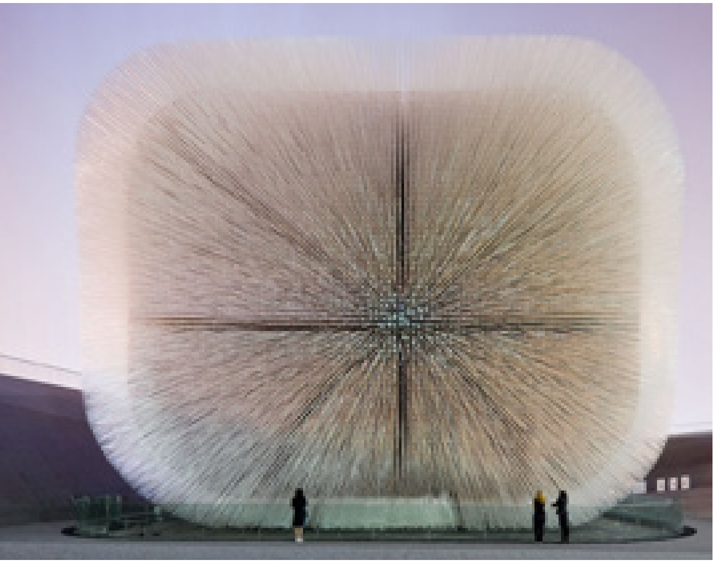
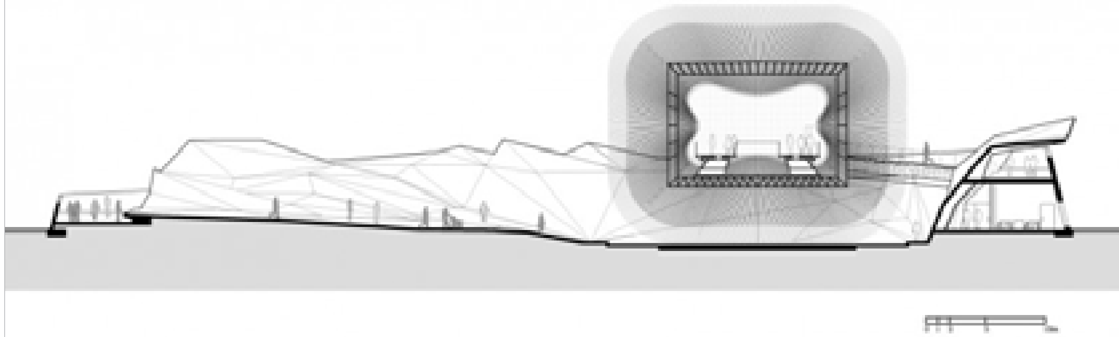
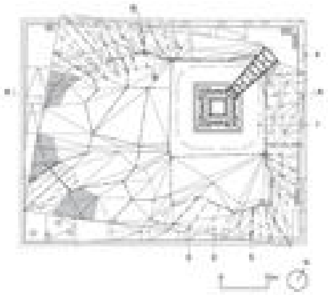


Fig 4.81 UK Pavilion for Expo 2010 Shanghai, China, designed by Heatherwick Studio

Expo 2010 Shanghai China was held on the banks of the River Huangpu in Shanghai from 1 May to 31 October 2010. Over 73 million people visited and 246 countries and international organisations took part. The competition to design the UK Pavilion for the event was won by a team led by Heatherwick Studio. The work of construction managers Mace, lead engineers Adams Kara Taylor [AKT] and service engineers Atelier Ten, along with highly skilled Chinese contractors, contributed to the pavilion being awarded the Gold Medal for pavilion design.

Heatherwick Studio insisted on simplicity and clarity to drive the design of the pavilion, focusing on the relationship between nature and cities. The pavilion became a ‘cathedral of seeds’, which are immensely significant for the ecology of the planet and fundamental to human nutrition and medicine. Seeds seemed the ultimate symbol of potential and promise and the design team began working with the Royal Botanic Gardens at Kew, which had previously set up the Millennium Seed Bank Partnership, whose mission is to ‘collect the seeds of 25% of the world’s plant species by 2020’.[36] The seeds for the pavilion were sourced from China’s Kunming Institute of Botany, a partner in the Millennium Seed Bank Partnership. 217,300 seeds were cast into the tips of each of the acrylic rods that gave the pavilion its hair-like appearance, swaying and moving in the wind with dynamic effect, reacting to its surroundings.





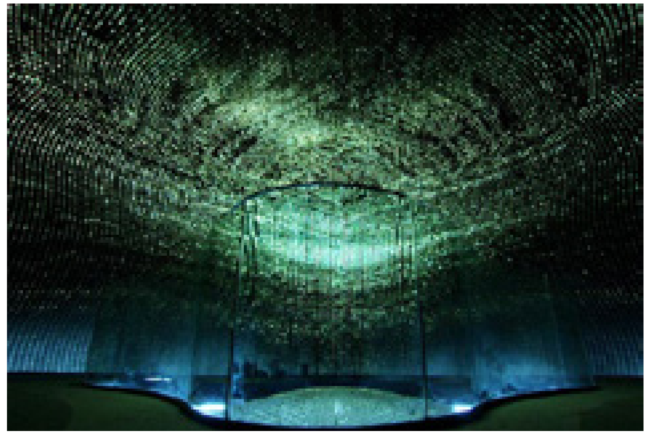


Fig 4.82 [top] UK Pavlion for Expo 2010 Shanghai – site section

Fig 4.83 [above] UK Pavilion for Expo 2010 – site plan

Fig 4.84 [right] Inside the Seed Cathedral

The optical fibre filaments, which ran from end to end of the acrylic rods, were particularly responsive to external light conditions; the movement of the clouds created fluctuating luminosity inside the pavilion. By night, light sources inside each rod illuminated the tips of the ‘hairs’ inside and out.

The pavilion occupied one-fifth of the allocated site, and the rest of the site was landscaped into a public park, enabling visitors to relax and observe the spectacle. The pavilion measured 15 x 15 x 10m and consisted of 60,000 identical clear acrylic rods that measured 7.5m in length. The simplicity and clarity of material selection and production ensured the thesis of the pavilion prevailed; it remained ‘a manifestation of its content’, exposing the seeds both internally and externally, cast at both ends of each acrylic rod.[37]

Fig 4.85 [left] Acrylic rods with seeds cast in the tip, showing aluminium sleeve and red plastic extrusions

Two-thirds of the rods' lengths were encased in aluminium. Externally, 1.5m of acrylic remained exposed, and this material shift was obvious with the clear acrylic appearing as a glowing halo around the metallic silhouette. There were a series of red plastic extrusions where the aluminium met the acrylic that allowed the two materials to move without scratching the acrylic. The two aluminium sleeves strengthened the acrylic rods and enabled rubber waterproofing rings to be placed between the inner and outer skin.[38] Heatherwick, AKT and materials consultants Smithers Rapra tested various acrylic and aluminium samples. The aluminium was designed to reinforce and strengthen the connections to the box, providing strength at the root of each rod to allow for flexibility and lateral movement. A team at the Tongji Institute of Environment for Sustainable Development conducted load tests. 'The fatigue failure of the aluminium and the acrylic was carefully considered because of the anticipated cyclic movement.'[39] The decision was made to refrain from boring holes through the aluminium fixings in the aluminium. The acrylic extrusions were 20 x 20mm and the larger aluminium sleeve was 30 x 30mm.

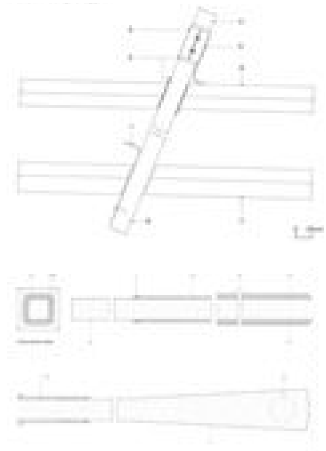


Fig 4.86–Fig 4.87 Drawing of the aluminium stiffening sleeve

The holes in the 1 metre thick wood diaphragm structure forming the visitor space inside the Seed Cathedral were drilled with great geometric accuracy to ensure precise placement of the aluminium sleeves through which the optic fibre filaments were inserted. This was achieved using 3D computer modelling data, fed into a computer controlled milling machine.[40]

Fig 4.88 Construction of the UK Pavilion for Shanghai Expo 2010 under construction

The material choice, fabrication methods and assembly each required precision design elements, tailored specifically for the pavilion. ‘We did a lot of tests about wind-loading, typhoon and earthquake conditions’, stated Katerina Dionysopoulou of Heatherwick Studio.[41] The local Shanghai climate determined the design parameters – having to cater for temperatures of 40°C, monsoon wind gusts of up to 120km/h and seismic activity. The design and engineering of the rods with the aluminium casings ensured that they could move with gentle winds and yet also withstand and resist typhoon loads.

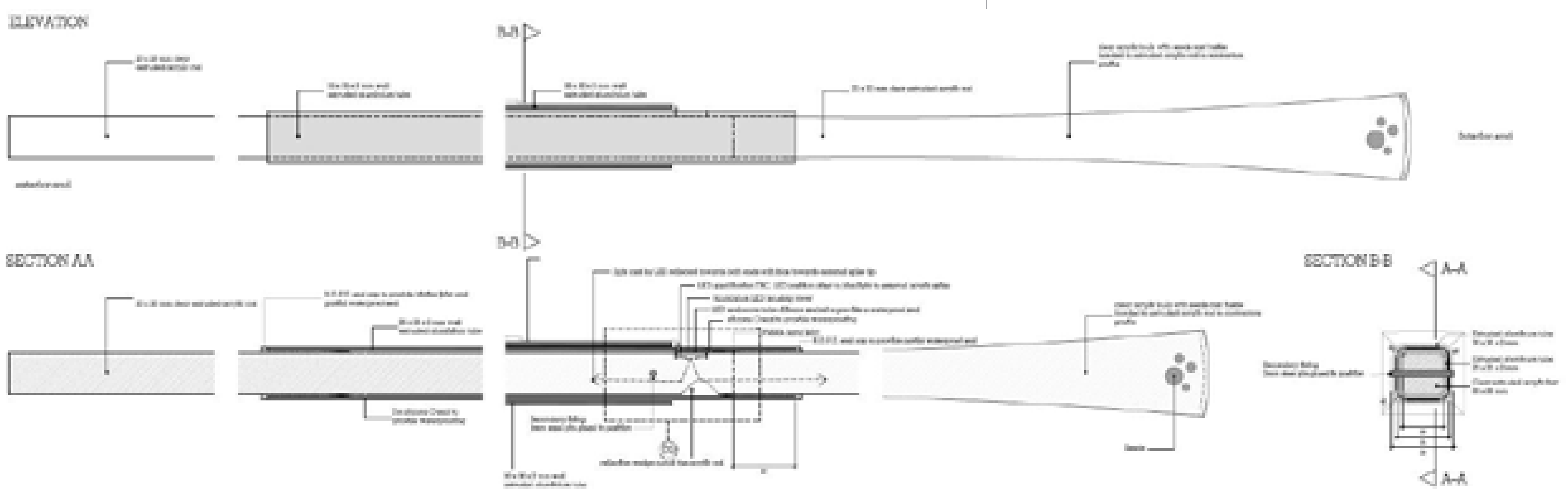
The ephemeral nature of the pavilion not only extended to its short six-month life span but was also exhibited in the way it was designed. It was the UK government’s intention that most of the materials of the pavilion would be reused or recycled at the end of the Expo and it was reported that ‘75% of the materials for the UK Pavilion have been sourced from within a radius of 300km around Shanghai.’[42]

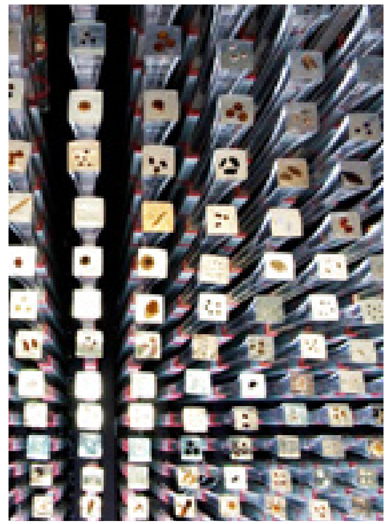
Fig 4.89 Drawing of acrylic rods, showing aluminium sleeve and LED light source

Fig 4.90 [bottom right] Detail view of the rods in situ

The pavilion was dubbed ‘Pu Gong Ying’, which translates as ‘the Dandelion’, by the Chinese public, relating to the metaphor of the dandelion seeds being blown away and dispersed with the breeze once Expo 2010 was over. The Seed Cathedral’s 60,000 optic hairs were distributed to hundreds of schools across China and the UK as a special legacy of the pavilion.[43] They are considered pieces of artwork and have become desirable and collectable. It is thought that the aluminium sleeves were collected for recycling.

Despite a host of interested buyers, there was never any intention to rebuild the pavilion. Hanif Kara, of project engineers AKT, said: ‘The pavilion was designed to live for a short time, so what it’s made from and how it’s made are temporary.’[44] According to Joe Morris, co-founder of Duggan Morris, pavilions are intended to be ‘fleeting, ephemeral, captured moments of an idea.’[45]





Notes

1 M. Stacey (ed.) (2014), *Aluminium and Durability: Towards Sustainable Cities*, Cwningen Press, Llundain.
2 *United Nations Refugee Agency*, www.unhcr.org/ (accessed January 2014).
3 *IKEA Foundation*, www.ikeafoundation.org (accessed January 2014).
4 For quantitative results, see: M. Stacey (ed.) (2014), *Aluminium and Durability: Towards Sustainable Cities*, Cwningen Press, Llundain.
5 B. Vale (1995), *Prefabs: A History of the UK Temporary Housing Programme*, E & FN Spon, London, p. 15.
6 B. Finnimore (1985), *The A.I.R.O.H. house: industrial diversification and building state policy*, Construction History, 1, p. 61.
7 National Museum Wales (2007), *From Blitz to prefab: how the Second World War altered housing in Wales*, 26 April, available online at www.museumwales.ac.uk/en/rhagor/article/blitz_prefab/ (accessed February 2015).
8 B. Finnimore (1985), *The A.I.R.O.H. house: industrial diversification and building state policy*, Construction History, 1, p. 63.
9 B. Vale (1995), *Prefabs: A History of the UK Temporary Housing Programme*, E & FN Spon, London, p. 16.
10 Ibid.
11 Ibid.
12 Ibid.
13 Ibid, p. 18.
14 B. Finnimore (1985), *The A.I.R.O.H. house: industrial diversification and building state policy*, Construction History, 1, p. 68.
15 J. A. Hopping (2006), *Development of Rapidly Deployable Structures for Military Applications: A System Based Approach to Command Post Facilities* (thesis), MIT, available online at http://dspace.mit.edu/bitstream/handle/1721.1/36747/78251990.pdf?seque (accessed April 2015).
16 B. Addis (2007), *Building: 3,000 Years of Design, Engineering and Construction*, Phaidon, London, p. 508.
17 D. Cruickshank (1995), *The Dome of Discovery*, Architectural Review, 197(1175), pp. 80–85, available online at www.packer34.freeserve.co.uk/dome.htm (accessed February 2015).
18 *Front Row* (2011) BBC Radio 4, 8 March, available online at www.bbc.co.uk/programmes/b00z6dvq (accessed December 2013).
19 N. Peters (2013), *Jean Prouvé: 1901–84: The Dynamics of Creation*, Taschen, Cologne, p. 7.
20 P. Sulzer (2004), *Jean Prouvé: Œuvre complete / Complete Works, Volume 3: 1944–1954*, Birkhäuser, Basel, p. 343.
21 Culture Communication France (1993), *Supplementary Inventory of Historical Monuments*, February, available online at www.culturecommunication.gouv.fr/Politiques-ministerielles/Monuments-historiques/Intervenir-sur-un-monument-historique/Les-immeubles-inscrits-au-titre-des-monuments-historiques (accessed March 2015).
22 A. Vénacque (2001), *Jean Prouvé: Le pavillon du Centenaire de l'aluminium*, Editions Jean-Michel Place, Paris, p. 39.
23 R. Klein (2012), *Le pavillon du centenaire de l'aluminium, un patrimoine en pièces*, in F. Graf and Y. Delemontey (eds), *Architecture industrialisée et préfabriquée: connaissance et sauvegarde*, École polytechnique fédérale de Lausanne, Presses polytechniques et universitaires romandes, Lausanne, p. 136.
24 The sale was organised by the Artcurial auction house and took place in Paris on 23 and 24 November 2010. The doors sold for €180,000 and have since been re-auctioned by Sotheby's Paris on 6 June 2012.
25 P. Sulzer (2004), *Jean Prouvé: Œuvre complete/Complete Works, Volume 3: 1944–1954*, Birkhäuser, Basel, p. 339.
26 Recorded from an email conversation between Richard Klein and Laura Gaskell in December 2013.
27 M. Stacey (2012), *Digital Craft in the Making of Architecture*, in B. Sheil (ed.), *Manufacturing the Bespoke: Making and Prototyping Architecture*, Wiley, Chichester, pp. 60–62.
28 P. Buchanan (1993), *Renzo Piano Building Workshop: Complete Works: Volume 1*, Phaidon, London, p. 112.
29 Peter Buchanan records that many contemporary critics observed that Renzo Piano's buildings 'were mere assemblies [of components] rather than *real* architecture'. Ibid., p. 113, emphasis in original.

30 M. Stacey (2008), *That just about wraps it up for the Cellophane House*, Building Design, 31 October, available online at www.bdonline.co.uk/that-just-about-wraps-it-up-for-the-cellophane-house/3126260.article (accessed December 2013).
31 M. Stacey (2010), *The Future Builds on Aluminium: Architecture Case Studies*, in L. Katgerman and F. Soetens (eds), *New Frontiers in Light Metals: Proceedings of the 11th International Aluminium Conference*, IOS Press, Amsterdam, p. 227.
32 KieranTimberlake (2011), *Cellophane House™*, KieranTimberlake, Philadelphia, PA, p. 30.
33 M. Stacey (2008), *That just about wraps it up for the Cellophane House*, Building Design, 31 October, available online at www.bdonline.co.uk/that-just-about-wraps-it-up-for-the-cellophane-house/3126260.article (accessed December 2013).
34 KieranTimberlake (2011), *Cellophane House™*, KieranTimberlake, Philadelphia, PA, p. 118.
35 R. Gregory (2009), *Serpentine Pavilion by SANAA, Serpentine Gallery, Hyde Park, London, UK*, Architectural Review, 1 August, available online at www.architectural-review.com/serpentine-pavilion-by-sanaa-serpentine-gallery-hyde-park-london-uk/8601012.article (accessed December 2013).
36 Architonic, *UK Pavilion, Shanghai World Expo*, available online at www.architonic.com/aisht/uk-pavilion-shanghai-world-expo-heatherwick-studio/5100437 (accessed January 2013).
37 Heatherwick Studio, *UK Pavilion: Shanghai Expo 2010*, available online at www.heatherwick.com/uk-pavilion/ (accessed December 2013).
38 T. Heatherwick (2013), *Making*, paperback edition, Thames & Hudson, London, p. 452.
39 H. Kara (2010), *Structural engineering: AKT's role in Heatherwick Studio's Shanghai Expo pavilion*, Architects' Journal, 8 July, available online at http://m.architectsjournal.co.uk/8602807.article (accessed February 2015).
40 S. Jordana (2010), *UK Pavilion for Shanghai World Expo 2010 / Heatherwick Studio*, ArchDaily, 3 May, available online at www.archdaily.com/?p=58591 (accessed January 2014).
41 W. Hunter (2010), *British Pavilion by Heatherwick Studio, Shanghai, China*, Architectural Review, 14 May, available online at www.architectural-review.com/british-pavilion-by-heatherwick-studio-shanghai-china/5217803.article (accessed December 2013).
42 Architonic, *UK Pavilion, Shanghai World Expo*, available online at www.architonic.com/aisht/uk-pavilion-shanghai-world-expo-heatherwick-studio/5100437 (accessed January 2013).
43 Dezeen (2010), *UK Pavilion at Shanghai Expo 2010 by Thomas Heatherwick*, 31 March, available online at www.dezeen.com/2010/03/31/uk-pavilion-at-shanghai-expo-2010-by-thomas-heatherwick-2/ (accessed February 2015).
44 R. Waite (2010), *Shanghai 2010: Seed Cathedral' will not be sold says FCO*, Architects' Journal, 2 September, available online at www.architectsjournal.co.uk/news/daily-news/shanghai-2010-seed-cathedral-will-not-be-sold-says-fco/8605455.article (accessed February 2015).
45 Ibid.

FIVE

global aluminium reserves in the built environment

Global Aluminium Reserves in the Built Environment

This chapter examines the potential release of aluminium from architecture and infrastructure to recycling. Architecture and infrastructure represent a significant economic and cultural investment providing purposeful long-term functions within the built environment. Thus aluminium used in architecture has a performative role, including providing shelter, comfort and well-being, over a long life and is not just a readily available material and energetic resource to be tapped into through recycling. Buildings are more than the sum of their functional parts. Design and cultural values within architecture often result in reinvention rather than demolition, as set out in Chapter Two. There is, however, significant potential for the recovery of aluminium when buildings and infrastructure are demolished, renovated or retrofitted, as discussed in Chapter Two.

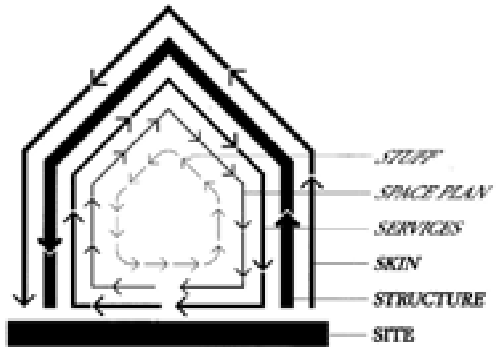
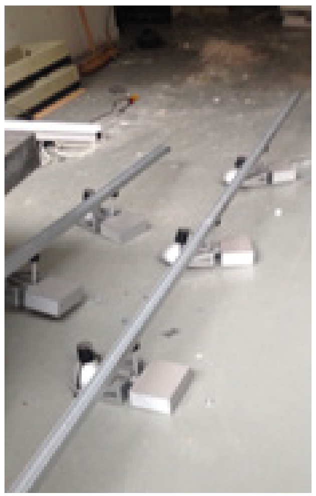


Fig 5.1 Shearing Layers of Change by Stewart Brand – a building can be seen as a series of layers, change is dependant on the durability of its components and other drivers of change

Fig. 5.2 [below] Extruded aluminium lighting support track with lights in situ being stripped from a shop interior, Nottingham, 2015 – these components could be reused or recycled



The Potential Release of Aluminium from Renovation and Retrofit

During the renovation and retrofit of a wide range of architectural typologies, there is the potential for the release of aluminium components from minor items such as carpet trims or complete glazing systems, as recorded in Chapter Two. It is pertinent to note the findings of the TU Delft study *Collection of Aluminium from Buildings in Europe;* even buildings that were originally built without any aluminium nevertheless yield significant quantities of aluminium for recycling upon demolition.[1] In Chapter Two, it was observed that the refurbishment of the New Bodleian Library involved the removal of approximately 8,000 tonnes of construction material from the original building. As previously noted, the anodised aluminium windows, which are almost 80 years old, have been cleaned and retained. Some building typologies are more likely to incur short-term change, as is evident in the retail sector, where both internal fit-out and shop fronts are subject to corporate and market-driven change.

Whilst renovation and retrofit do offer a significant opportunity for urban mining and the release of aluminium to recycling, a recent development in low-energy architecture for commercial office buildings, pioneered by Rab and Denise Bennetts of Bennetts Associates, may limit such opportunities for minor aluminium items in the future.[2] Figure 5.3 shows the exposed concrete soffits of the Powergen Headquarters, Warwickshire, UK, completed in 1994.[3] If architects and engineers design on the basis of a high degree of integration of performative functions, the possibility of minor

Fig 5.3 Powergen Headquarters, Warwickshire, designed by Bennetts Associates

and early changes to the building fabric is greatly reduced. This approach to low-energy office design provides thermal mass to dampen the peaks and troughs of thermal gains. The interior of the Powergen building is cooled at night by automated aluminium windows controlled by a Building Management System [BMS], thus providing comfortable conditions without the need for air conditioning. This holistic approach results in an integration of structure, interior and architecture where change is only required to signage, lighting, decoration and furniture and not to building fabric. Only if the building is demolished or the curtain walling and windows are replaced will it release significant quantities of aluminium from its windows and curtain walling.

The Powergen Headquarters was one of the first to adopt this approach to low-energy office design, which Bennetts Associates also implemented in the design of Wessex Water Headquarters, completed in 2000. It is equally applicable to university buildings, such as the Informatics Building at the University of Edinburgh, 2008, also by Bennetts Associates.[4] Other examples in the UK include the Inland Revenue Building in Nottingham by Hopkins Architects, 1994, and Heelis, the National Trust Headquarters, by Feilden Clegg Bradley Studios, 2005, as discussed in Chapter Six and illustrated on page 236. A Dutch example is the Expertex Textile Centrum, designed by Brookes Stacey Randall with IAA and completed in 2002. Morphosis also used this design strategy in San Francisco, California for the United States Federal Building, which when completed in 2007 was the first major office building in North America to be naturally ventilated in 70 years. The Federal Building uses only 45 per cent of the energy of a typical General Services Administration office.[5]

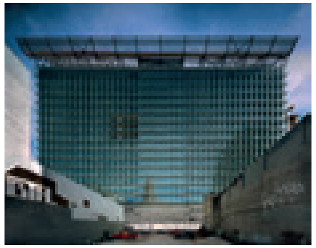


Fig 5.4 United States Federal Building, designed by Morphosis

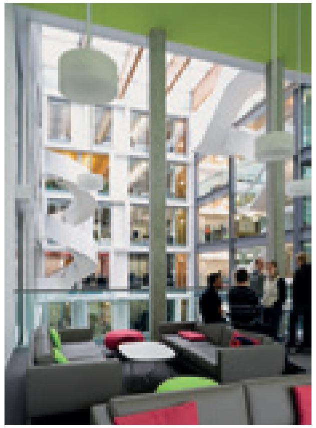


Fig 5.5 Breakout space and atrium of the Informatics Building, architect Bennetts Associates

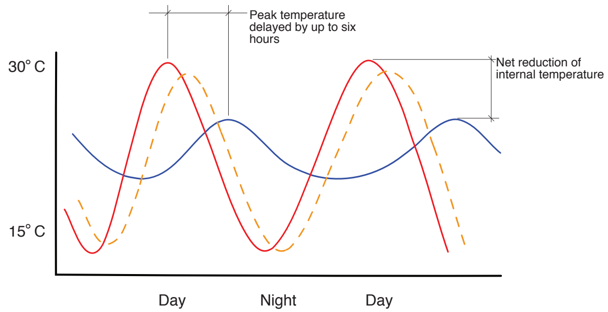


Fig 5.6 Fabric energy storage provided by exposed thermal mass

Fig 5.7 Exposed waveform concrete soffit of the United States Federal Building

Fig 5.8 Inland Revenue Building, Nottingham, designed by Hopkins Architects

Aluminium Industry Mass Flow Models

A number of mass flow models have been developed by the IAI and the Norwegian University of Technology, mapping regional supply and demand of aluminium products by alloy groups. These models for China, Europe, Japan, South America, the Middle East, North America, Other Asia and Other Producing Countries over the period from 1888 to 2030 enable industry, business strategists and policy makers to increase the efficiency in recycling of aluminium alloys, to understand the future availability and location of aluminium scrap, and to plan for future metal demand. Figure 5.9 schematically examines the annual inputs and outputs for the overall IAI Global Mass Flow Model. Figure 5.10 is the overall IAI Global Mass Flow Model for 2013.[6]

For this study, the mass flow models were used to track the aluminium flow in a consistent way, for the building and construction sector. It will help us to understand the roles that various regions have played historically, and will play in the future, in the aluminium construction market. It will also reveal the build-up of the aluminium stock in buildings, where the aluminium fulfils an important performative role, and the recycling of this scrap within these regions when the buildings and infrastructure reach the end of their life.

Since raw data quality for final product shipments, product trade, lifetimes and collection rates may vary significantly from region to region, results should be reviewed cautiously. This merits further research collaborations, as discussed in the Interim Conclusion.

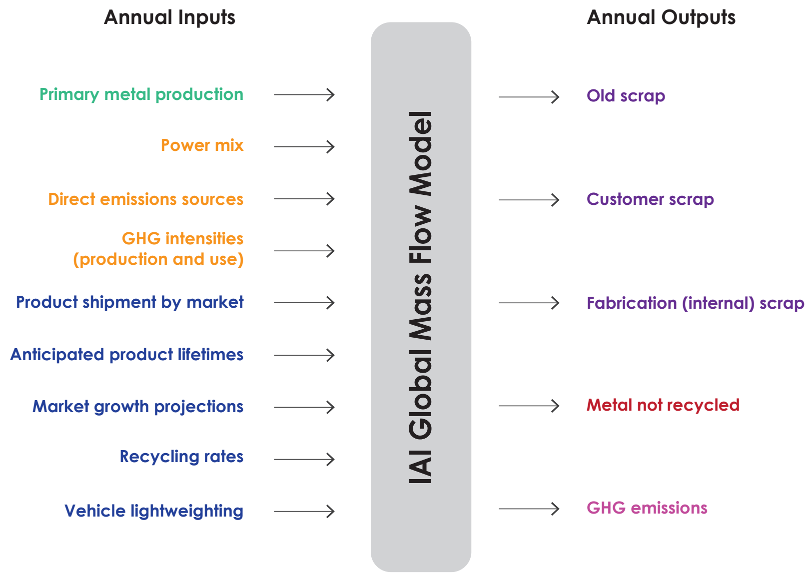


Fig 5.9 Inputs and outputs annually for the IAI Global Mass Flow Model

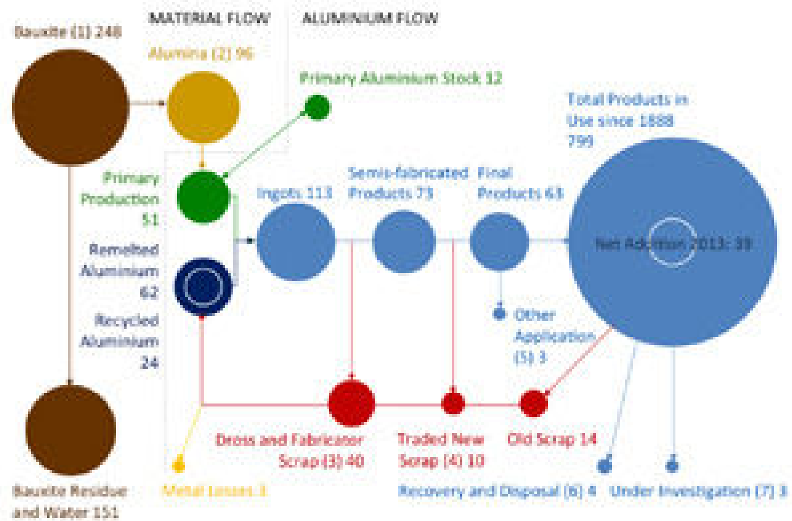


Fig 5.10 IAI Global Mass Flow 2013 (quantities in million tonnes)

How the Life Expectancy Scenarios Were Developed

The life expectancy scenarios for architecture and infrastructure in each region have been developed based on the research undertaken and set out within this book. This has been combined with the research on durability set out in *Aluminium and Durability*,[7] and further informed by a literature study and regionally specific typological and demographic research. There is evidence in all regions that some uses of aluminium in architecture are short term, either because the projects are planned to have a short life, as set out in Chapter Four, or because the building or building components are subject to rapid change – for example, land use, such as road widening, or elements within an office or shop fit-out that are subject to corporate change or market forces. The regions with the buildings that have the longest predicted life expectancies both contain the oldest examples of the use of aluminium and have developed a cultural approach to architecture whereby heritage is highly valued through the retention of built fabric. Within the life expectancy scenarios set out below, demolition, refurbishment and retrofit flows have not been separated out. Another major driver is the improved thermal performance of windows and curtain walling, including air infiltration rates. Will the performance of such products continue to develop over the next 30-60 years?

The evidence found in this study suggests that timescales for demolition and refurbishment are longer than many expect. To restate key findings from Chapter Two, the average age at the time of reglazing of major North American projects studied in this research is over 60 years. Using the beta version of the database on *facaderetrofit.org*, the average age of buildings at the time of curtain-walling retrofit is almost 40 years, including projects in Peru, Norway, North America and the UK. For reinvention and over-cladding, the average age of the buildings is over 70 years, with projects mainly in North America although with some examples from Norway and Germany. Interestingly, this research establishes an average age of buildings for window replacement of over 70 years. A focus has been placed on tall buildings, as they are a building typology that from the 1950s onwards became dependent on the use of aluminium, particularly in curtain walling.

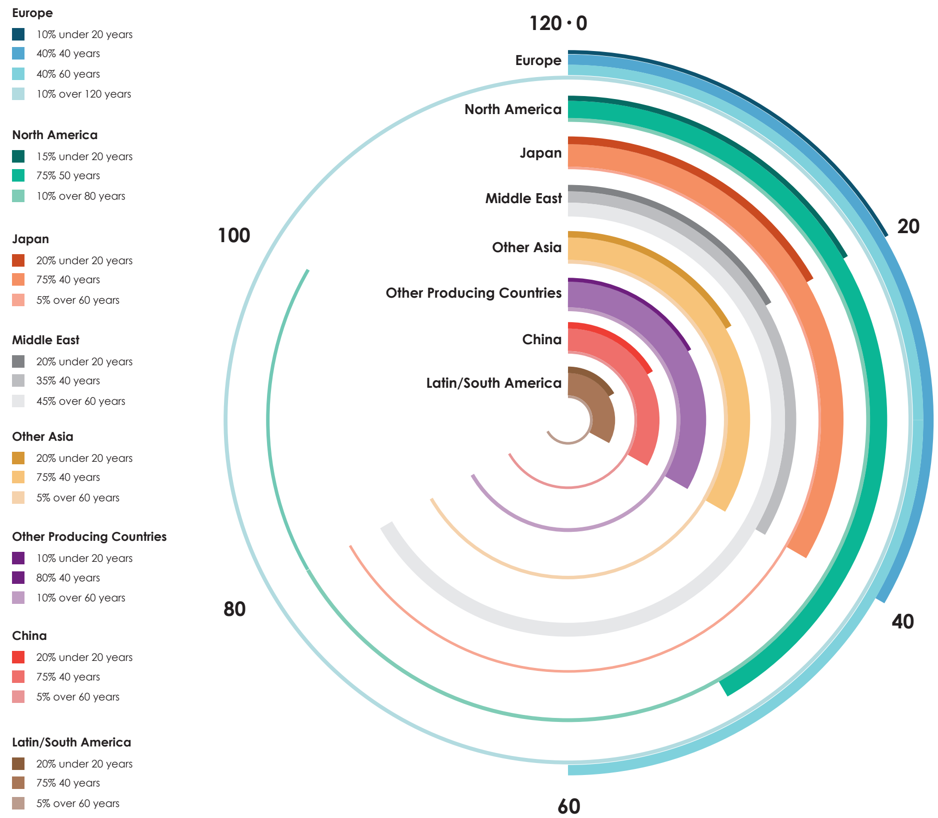


Fig 5.11 Anticipated life expectancy scenarios for the eight IAI regions (The regions are ordered in terms of anticipated longevity. Please note these are not building life expectancies alone; they include retrofit, for example replacement curtain walling)

The timescales within regions of rapid urbanisation have been kept relatively shorter due to newness of construction both of tall buildings and curtain walling, neither of which is likely to require action including upgrading or replacement in the immediate future. The average age of tall buildings over 150m high in each region is:

- **China**: 10 years;
- **Europe**: over 12 years;
- **Japan**: over 13 years;
- **Latin/South America**: over 18 years;
- **the Middle East**: over 6 years;
- **North America**: over 30 years;
- **Other Asia**: 10 years;
- **Other Producing Countries**: over 16 years.

This is summarised in Figure 5.12 and is based on figures for 2014 from the Council on Tall Buildings and Urban Habitat [CTBUH] database, rounded to whole numbers and harmonised by the author with the IAI's regions within its mass flow model.[8] As discussed in Chapter Two, only seven projects over 150m high have ever been demolished worldwide – all located in North America.

Within each region specific factors, where identifiable, are discussed, including how they may have influenced the life expectancy scenarios.

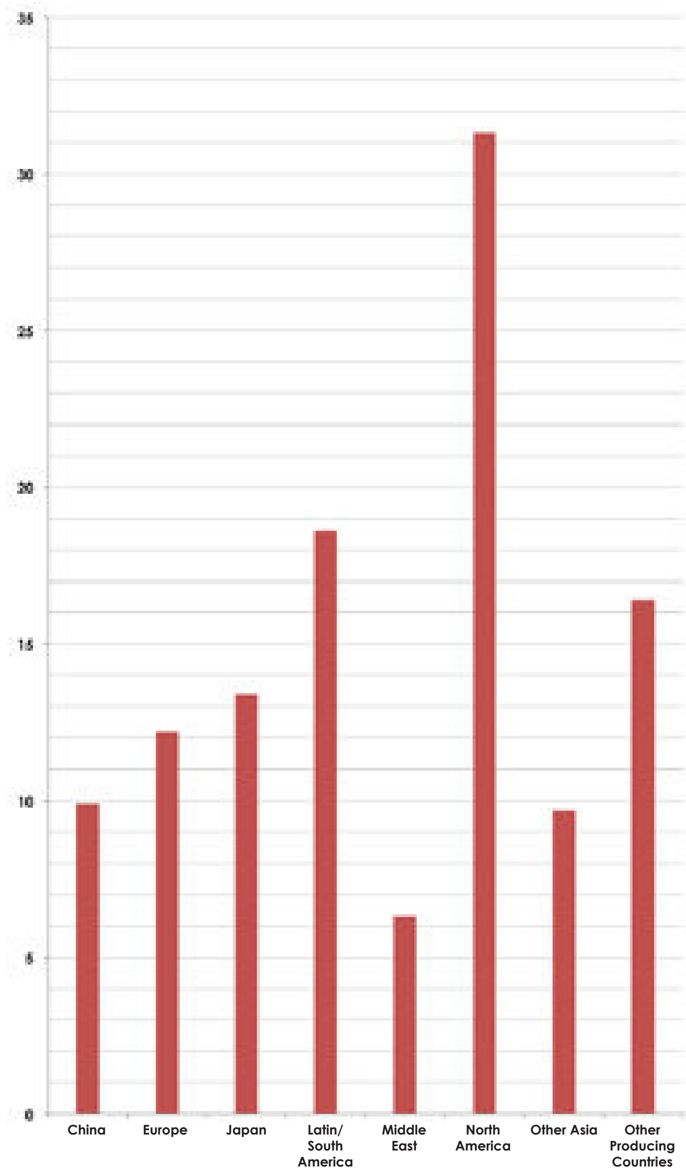


Fig 5.12 Average age of tall buildings over 150m high globally by region, early 2015 (not including under construction)

Architecture and Infrastructure Life Expectancy Scenarios

China

Architecture and infrastructure life expectancy scenarios: 20 per cent under 20 years; 75 per cent 40 years; 5 per cent over 60 years – effective maximum 80 years.

China has experienced a period of very rapid urbanisation since adopting open-door policies in 1978, following the end of the Cultural Revolution in 1976, with the proportion of the population living in urban areas increasing from 18 per cent in 1978 to 45 per cent in 2007.[9] Hu and colleagues modelled the scenarios for the life expectancy of rural and urban housing in China.[10] The short-life housing, especially in rural areas, was built between 1966 and 1976. The demand for aluminium for building and construction in China in 1976 was around 90,000 tonnes. Following the period of rapid urbanisation, this demand had risen to approximately 5 million tonnes by 2007.

Hu and colleagues observed that 'in China all land belongs to the state and is leased for housing development. The land lease period is normally 70 years.'[11] Based on this and the improvement in construction quality likely to arise from the sale of housing at market prices, the life expectancy of urban housing in China could become 75 years. In China, the average age of tall buildings over 150m high is almost 10 years; however, this is based on a total of 1,088 projects,[12] which may prove to have a structural life expectancy of at least 100 years, but will probably require cyclical retrofits of windows and curtain walling.[13] The earliest building of this height was constructed in China in 1973; however, over 1,010 such buildings were completed between 1996 and 2014.[14] It should also be noted that the CTBUH data for China includes Hong Kong, which was returned by the UK to China in 1997 and is now a Special Administrative Region.

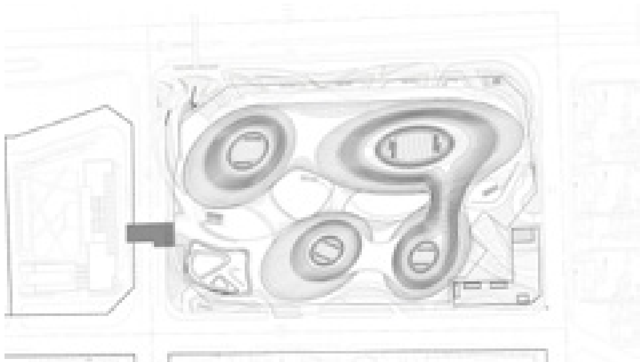


Fig 5.13 Site plan of Galaxy SOHO

Fig 5.14 Galaxy SOHO designed by Zaha Hadid Architects, Beijing, China is a 360,000m^2 mixed-use scheme where aluminium is the primary cladding material

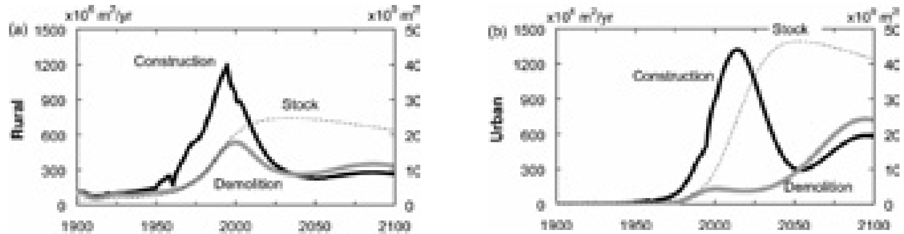


Fig 5.15 Simulation results for housing stocks and flows in rural and urban China (Stocks are measured on the right axis, and flows on the left) – based on Hu et al. 2010

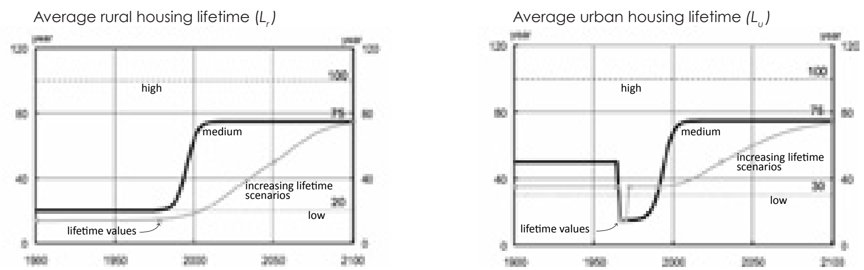


Fig 5.16 Average rural and urban housing lifetime based on historical data (1900–2006) from China Statistical Yearbooks, NBSC and projections from 2006–2100, (for each external parameter a low, medium, and high variant are estimated for the future period) – based on Hu et al. 2010

Europe

Architecture and infrastructure life expectancy scenarios: 10 per cent under 20 years; 40 per cent 40 years; 40 per cent 60 years; 10 per cent over 120 years – effective maximum 140 years.

Europe is home to the oldest historic examples of aluminium-rich buildings, and in this region cultural continuity is perceived as being achieved through preservation, leading to long lifetimes for buildings. However, change is also a factor, particularly in the form of post-industrial regeneration and cyclical patterns of change in out-of-town shopping developments, as well as retail and office fit-outs. Improving the thermal performance of building envelopes, including minimising air infiltration rates, also appears to be a major driver of retrofit in Europe.

In 1950, the population in Europe was 549 million. This steadily increased to 742 million by 2013.[15] Throughout this period, the majority of people in Europe lived in towns and cities, rising from 52 per cent in 1950 to 72 per cent by 2010.[16] The demand for aluminium in building and construction was 67,000 tonnes in 1950, increasing steadily to 737,000 tonnes in 1970 and 2.5 million tonnes by 2010.[17] This increase was a response to the demand from population and city growth, including urban infill projects.

Fig 5.17 Commerzbank Building, Frankfurt, Germany, architect Foster + Partners, completed in 1997

Fig 5.18 Frankfurt skyline focussed on the Commerzbank Building

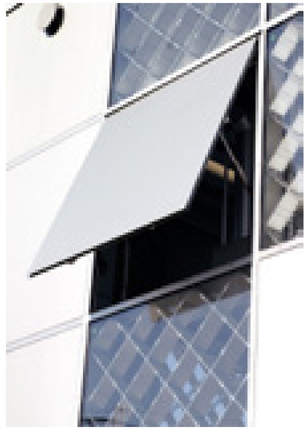


Fig 5.19 A flush detailed ventilator articulates the 1200 mm module of this prototype Aluminium House in Kyushu, Japan, designed by architect Riken Yamamoto & Fieldshop

Japan

Architecture and infrastructure life expectancy scenarios: 20 per cent under 20 years; 75 per cent 40 years; 5 per cent over 60 years – effective maximum 80 years.

Japan is a highly urbanised nation, with over 75 per cent of the population living in urban areas. Since 2007, it has experienced a steady decline in population, with an overall decrease of over 250,000.[18] In Japan, the domestic demand for aluminium for building and construction peaked at just 900,000 tonnes in 1991 and by 2012 this demand had fallen to just over 500,000 tonnes.[19]

Although this country was an early adopter of modern architecture during its reconstruction after the Second World War, ensuring cultural continuity in Japan is a matter of rebuilding rather than preservation, which leads to shorter building lifetimes than anticipated in Europe. Architect Tadao Ando, Pritzker Prize Laureate in 1995, has observed of the Ise Shrine:

> The shrine is completely rebuilt every twenty years in accordance with the practice of *shikinen-sengu*, a custom, unparalleled elsewhere in the world, of the regular removal of a shrine according to a fixed cycle of years. This custom, believed to have been established in the Nara period (around AD750), has been nearly faithfully observed until the present. In the shrine compound are two alternate sites, and while one shrine is still intact, another, identical down to the smallest measure, is built on the adjacent site, the old shrine being demolished after the ritual of *sengu* … In this way, through the shrine's rebirth every twenty years for over a millennium, an ancient mode of architecture has reached us today virtually unchanged.[20]

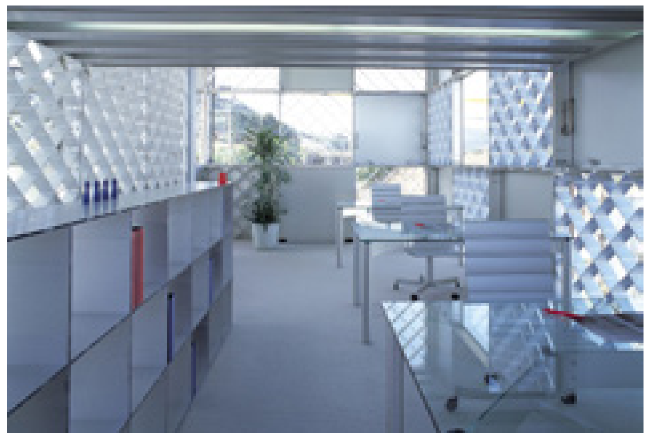


Fig 5.20 Interior of the prototype Aluminium House, opened during March 2004 in Kyushu

Latin/South America

Architecture and infrastructure life expectancy scenarios: 20 per cent under 20 years; 75 per cent 40 years; 5 per cent over 60 years – effective maximum 80 years.

Taking Brazil and Chile as two sample countries in this region, the population of Brazil in 2008 was over 190 million with over 83 per cent living in urban areas,[21] whereas in Chile in 2008 the population was over 16.5 million with approximately 85 per cent living in urban areas.[22]

In Latin/South America, the average age of tall buildings over 150m high is over 18 years, revealing that this region was a relatively early adopter of this form of urban architecture; therefore the above scenarios may understate the life expectancy of buildings in this region. In Latin/South America, the demand for aluminium for building and construction in 2008 was about 240,000 tonnes.[23]

The Middle East

Architecture and infrastructure life expectancy scenarios: 20 per cent under 20 years; 35 per cent 40 years; 45 per cent over 60 years – effective maximum 80 years.

Taking the United Arab Emirates [UAE] as an example, very rapid urbanisation has taken place since the mid-1960s. The population of the UAE in 1963 is estimated to have been 95,000; by 2013, this had risen to over 9.3 million. In Abu Dhabi, the population in 1965 was estimated at 50,000; by 2013, this had risen to over 920,000.[24]

Between the mid-1970s and the present day, Abu Dhabi has been transformed from a largely masonry-built town in a desert setting to one of the world's largest urban agglomerations of skyscrapers built in the twenty-first century. The average age of tall buildings over 150m high in the Middle East is just 6 years. The first of 256 projects of this height constructed in the region was completed in 1994; however, the vast majority of these projects, 224, were completed between 2006 and 2014.[25] These tall buildings may prove to have a structural life expectancy of at least 100 years, but will probably require cyclical retrofits of windows and curtain walling.[26] In the Middle East, the demand for aluminium in building and construction during 2006 was approximately 400,000 tonnes, rising to an estimate of 590,000 tonnes in 2014.[27]

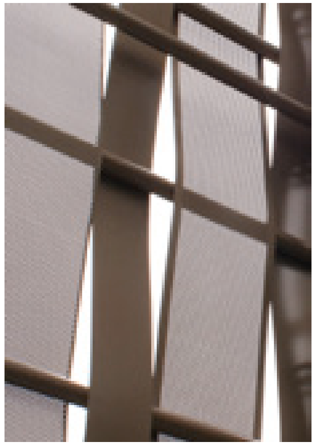


Fig 5.21 Detail of the perforated aluminium screen façade of the 2008 XVI Chilean Architecture Biennale Pavilion, Santiago, Chile, designed by Felipe Assadi & Francisca Pulido Architects

Fig 5.22 XVI Chilean Architecture Biennale Pavilion designed by Felipe Assadi & Francisca Pulido Architects

Fig 5.23 Abu Dhabi coastline, 1970

Fig 5.24 Abu Dhabi coastline, 2006

North America

Architecture and infrastructure life expectancy scenarios: 15 per cent under 20 years; 75 per cent 50 years; 10 per cent over 80 years – effective maximum 100 years.

As shown in *Aluminium and Durability*, North America was an early adopter of the skyscraper, particularly in Manhattan.[28] Although North America had a tradition of demolition and reconstruction in the twentieth century, there is now a growing interest in the preservation of architecture as a form of cultural continuity.[29] As observed in Chapter Two, the median lifetime for a commercial building in the USA is 70–75 years, as calculated by the Pacific Northwest National Laboratory for the US Department of Energy (2010).[30] In 2005, commercial buildings represented 39 per cent of the building stock of the USA.[31] Under LEED v4, the minimum life expectancy for LCAs is 60 years with a maximum of 120 years, and many practitioners are now calculating an 80-year life.[32] Therefore, it is reasonable to presume that the life expectancy of buildings in North America will increase during the twenty-first century.

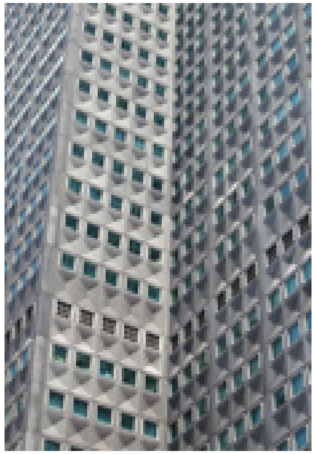


Fig 5.25 Aluminium cladding of the Alcoa Building, Pittsburgh, USA, architect Harrison & Abramovitz, completed in 1953, photographed 2013

Only 1 per cent of the tall buildings over 150m high in North America have been demolished, as discussed in Chapter Two. The average age of such buildings in North America is 30 years. If one looks at the construction of skyscrapers over 150m high in New York during the first age of this building type, between 1950 and 1964, 20 projects were completed, whereas between 2000 and 2014 50 projects of this kind were completed in the city.

However, detached housing dominates the building stock of North America, representing 80 per cent of the residential properties in 2009, with a total area of 21 million m^2. Of these detached houses, only exceptional cases will prove rich in aluminium as the predominant construction vernacular for detached houses in North America is timber frame. However, based on the TU Delft study *Collection of Aluminium from Buildings in Europe*, there may be a significant quantity of aluminium added to these projects over their lifetime.[33]

Retail formed 17 per cent of the building stock of North America in 2012, with a total area for commercial properties of 8 million m^2. Of the 19 largest shopping malls in this region, between 187,500 and 259,590m^2, the average age is 44 years. The newest, the Palisades Center in New York, was opened in 1998. However, the shop fronts and fit-outs of these malls are subject to cyclical

Fig 5.26 Alcoa Building skyline, Pittsburgh, USA, designed by Harrison & Abramovitz, photographed 2013

change and therefore contribute to shorter life cycle examples of the application of aluminium in construction. In comparison, the average age of shopping malls worldwide is 16 years, with a size range of between 125,000 and 557,419m^2.[34]

In North America, the domestic demand for aluminium for building and construction grew from approximately 240,000 tonnes in 1950 to about 720,000 tonnes in 1964. In comparison, the period between 2000 and 2014 saw the demand stay more or less stable, disregarding the decline in 2009, at over 1,200,000 tonnes.[35]

Other Asia

Architecture and infrastructure life expectancy scenarios: 20 per cent under 20 years; 75 per cent 40 years; 5 per cent over 60 years – effective maximum 80 years.

This region is a complex mix of countries including India, Indonesia, Malaysia, Singapore, Taiwan, Thailand and Vietnam. Many of the countries are experiencing rapid urbanisation, with tall buildings significantly contributing to this process. In Other Asia, the average age of tall buildings over 150m high is almost 10 years. The largest number of these projects is in South Korea, with 180 in total and 177 completed between 1997 and 2014. In comparison, Singapore saw 49 such projects completed in the same period. This city-state was a relatively early adopter of tall buildings, with the earliest dating from 1973. Thailand has 55 projects of this size completed between 1987 and 2014, whereas India has only 24, all dating from the twenty-first century.[36]

Therefore, as observed for other regions of the world, the significant presence of tall buildings may lead to the life expectancy of buildings being extended in this region, or at least in certain locations within the region.

In Other Asia, the demand for aluminium for building and construction was 340,000 tonnes in 1997 and by 2014 this demand was estimated to have increased to 900,000 tonnes.[37]

Other Producing Countries

Architecture and infrastructure life expectancy scenarios: 10 per cent under 20 years; 80 per cent 40 years; 10 per cent over 60 years – effective maximum 80 years.

This region includes Australia, Cameroon, Egypt, Guinea, Kazakhstan, New Zealand, Russia, Sierra Leone and South Africa – an even more diverse grouping of countries than Other Asia. However, this region has the third oldest collection of tall buildings of over 150m high, with an average age of over 16 years. This typology is dominated by Australia and Russia. Of the 117 tall buildings completed in the region between 1952 and 2014, 81 are in Australia, dating back to 1967, and 25 are in Russia, dating back to 1952. The development of tall buildings in Australia has been a steady and almost linear process. Those in Russia were completed between 1952 and 1955, with development not then recommencing until 1994; most projects have been completed in the twenty-first century.[38] Therefore, both Australia and Russia are likely to have longer life expectancy outcomes for the reasons stated above.

A specific example of recycling from Australia is the aluminium cladding of the dome of the Colonial Secretary's Building in Sydney, which was recycled after 100 years of use (1894–1994).

Fig 5.27 Cooled Conservatories at Gardens by the Bay, Singapore, designed by Wilkinson Eyre Architects, completed in 2012

Fig 5.28 Riverside Centre viewed from across the Brisbane River, Australia, designed by Harry Seidler & Associates, completed in 1986

Collection Rate for Aluminium from Architecture and Infrastructure

Based on the TU Delft study *Collection of Aluminium from Buildings in Europe*, a 95 per cent recovery rate for aluminium from the demolition of architecture and infrastructure has been used for all regions, as this is currently the only detailed study available.[39] Processing and melting rates vary from 95 per cent to 100 per cent depending on the available technology and the product. For sensitivity analysis, lifetimes ±5 years were analysed and a collection rate of 99 per cent was also modelled.

The following graphs shown in Figures 5.29 to 5.32 provide estimates of the available recycled aluminium from worldwide architecture and infrastructure on a regional basis.

Commentary

The graph in Figure 5.29 is dominated by China from 2000 onwards. The early adoption of aluminium in construction in Europe and North America, however, is also very evident.

The graph in Figure 5.30 is dominated by China, but only after 2020. It is pertinent to note that Hu and colleagues have observed: 'A better understanding of building lifetimes is, therefore, essential for forecasting future construction and demolition activities.'[40] The potential release of aluminium from architecture and infrastructure in North America is also very significant as it was an early and high-volume adopter of aluminium in construction whilst also having a strong tradition of reconstruction, similar to that of Europe.

The two graphs of sensitivity analysis (Figures 5.31 and 5.32) suggest that variation in life expectancy could have a more significant role in limiting the availability of aluminium scrap than further improvement in collection rates, even though the latter is becoming a common goal, as reported in Chapter Two.

Although this chapter has focused on aluminium scrap arising from the retrofit and demolition of architecture and infrastructure, it is important to emphasise the performative role of the 779 million tonnes of aluminium still in use in 2013 and accumulated since 1888, as shown in Figure 5.10, with buildings representing 37 per cent of this reserve.

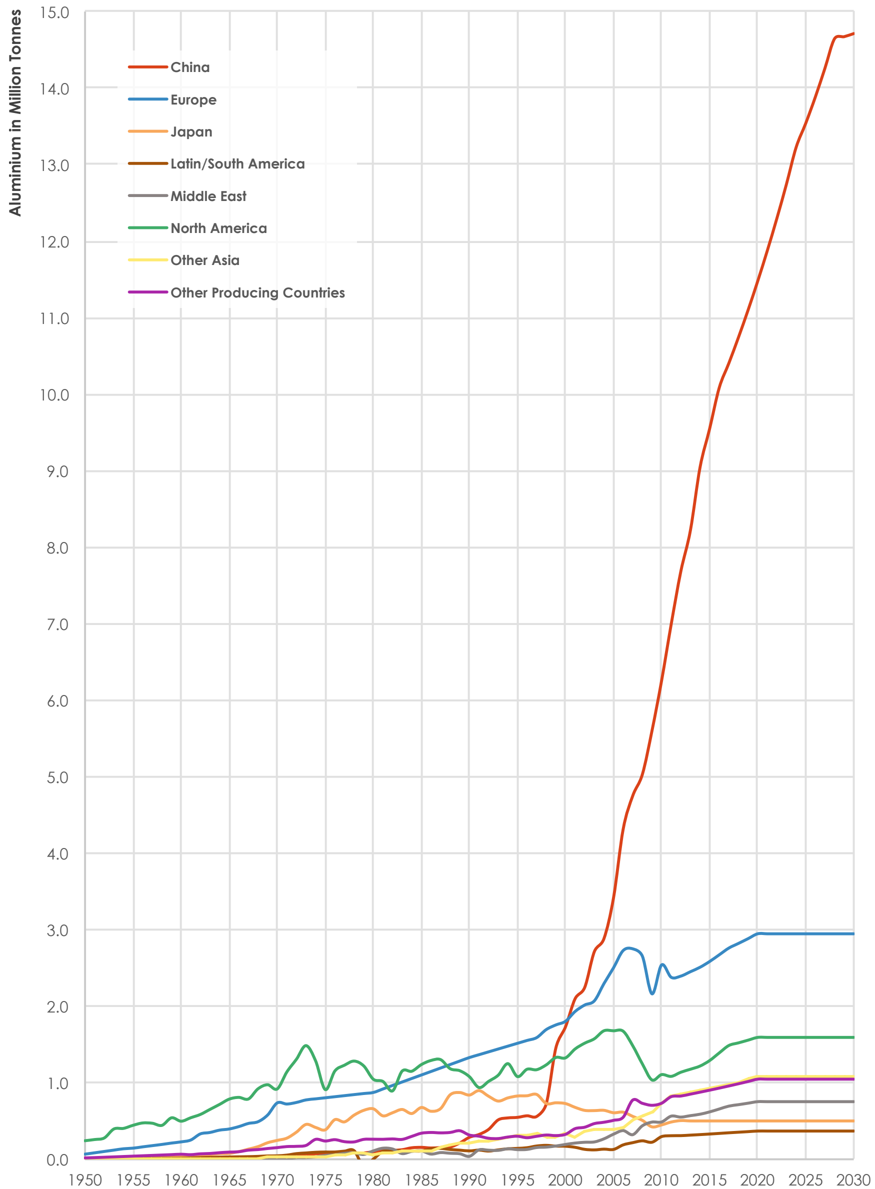


Fig 5.29 Aluminium building and construction products entering use, based on IAI Regional Mass Flow Models 2013

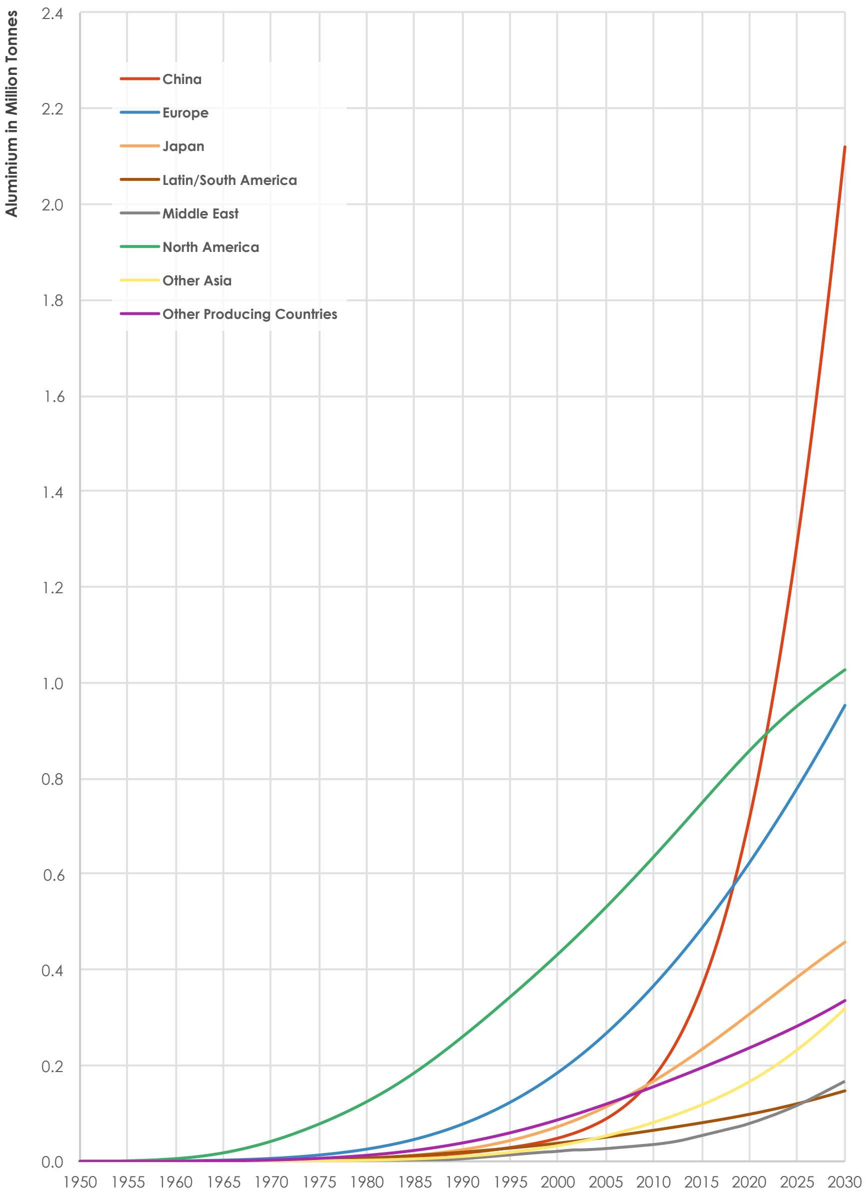


Fig 5.30 Regional potential release of old scrap from architecture and Infrastructure, based on IAI Regional Mass Flow Models 2013

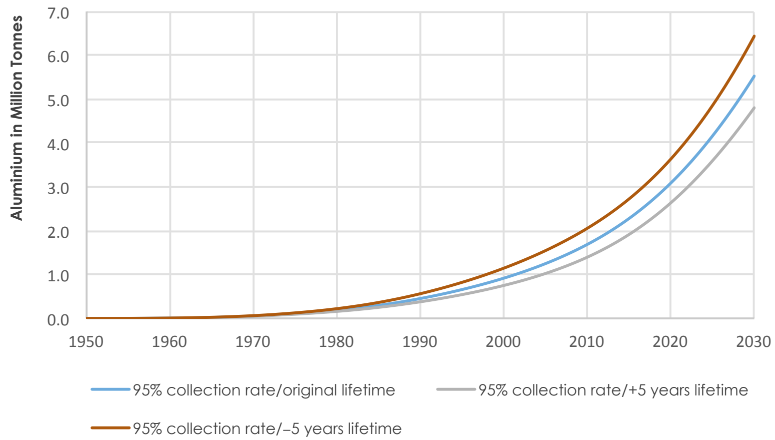


Fig 5.31 Global old scrap availability from architecture and infrastructure with anticipated life expectancies, shorter and longer lifetimes ±5 and 95% collection rate, based on IAI Global Mass Flow Model 2013

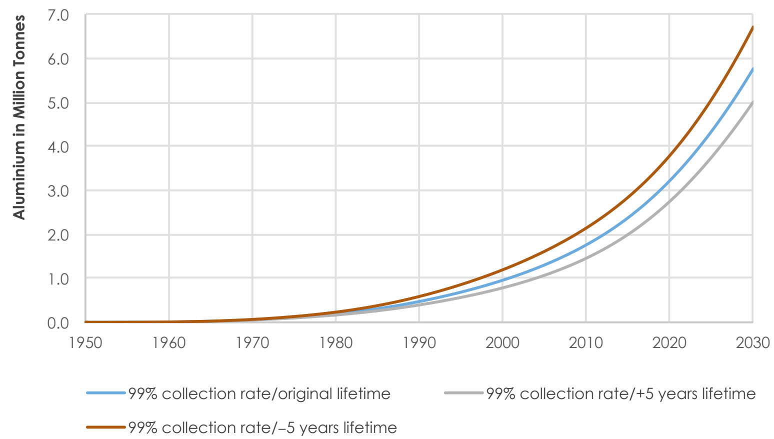


Fig 5.32 Global old scrap availability from architecture and infrastructure with anticipated life expectancies (see data above), shorter and longer lifetimes ±5 and 99% collection rate, based on IAI Global Mass Flow Model 2013

Notes

1 U. M. J. Boin and J. A. van Houwelingen (2004), *Collection of Aluminium from Buildings in Europe: A Study by Delft University of Technology*, EAA, Brussels, available online at recycling.world-aluminium.org/uploads/media/_TUDelftBrochure2004.pdf (accessed April 2015).
2 M. Stacey (2011), *Concrete: a studio design guide*, RIBA Publishing, London, pp. 213–233.
3 Ibid.
4 Ibid.
5 Ibid.
6 International Aluminium Institute (2015), *Global Aluminium Mass Flow Model*, IAI, London, available online at www.world-aluminium.org/publications (accessed March 2015).
7 M. Stacey (ed.) (2014), *Aluminium and Durability: Towards Sustainable Cities*, Cwningen Press, Llundain.
8 *The Skyscraper Center: The Global Tall Building Database of the Council on Tall Buildings and Urban Habitat*, www.skyscrapercenter.com/ (accessed January 2015).
9 M. Hu, H. Bergsdal, E. van der Voet, G. Huppes and D. B. Müller (2010), *Dynamics of urban and rural housing stocks in China*, Building Research & Information, 38(3), pp. 301–317.
10 Ibid.
11 Ibid., p. 303 and Endnote 3.
12 *The Skyscraper Center: The Global Tall Building Database of the Council on Tall Buildings and Urban Habitat*, www.skyscrapercenter.com/ (accessed January 2015).
13 M. Patterson, A. Martinez, J. Vaglio and D. Noble (2012), *New skins for skyscrapers: anticipating façade retrofit*, in A. Wood, T. Johnson and Q. Li (eds), *Asia Ascending: Age of the Sustainable Skyscraper City*, CTBUH, Chicago, IL, pp. 209–215.
14 *The Skyscraper Center: The Global Tall Building Database of the Council on Tall Buildings and Urban Habitat*, www.skyscrapercenter.com/ (accessed January 2015).
15 Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, *World Population Prospects: The 2012 Revision*, available online at esa.un.org/unpd/wpp/index.htm (accessed June 2015).
16 Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, *World Population Prospects: The 2014 Revision*, *CD-ROM Edition*, available online at esa.un.org/unpd/wup/CD-ROM/ (accessed June 2015).
17 International Aluminium Institute (2014), *Regional Mass Flow Model for Europe*, IAI, London, available online at www.world-aluminium.org/publications/ (accessed April 2015).
18 *United Nations Statistics Division*, unstats.un.org/unsd/default.htm (accessed March 2015).
19 International Aluminium Institute (2014), *Regional Mass Flow Model for Japan*, IAI, London, available online at www.world-aluminium.org/publications/ (accessed April 2015).
20 T. Ando (1995), *The Eternal within the Moment*, in F. dal Co (ed.), *Tadao Ando: Complete Works (1969–1994)*, Phaidon, London, p. 474.
21 *Sistema IBGE de Recuperação Automática*, www.sidra.ibge.gov.br/ (accessed March 2015).
22 Departamento de Estadísticas e Información de Salud, *Estadísticas población*, DEIS, available online at www.deis.cl/estadisticas-poblacion/ (accessed March 2015).
23 International Aluminium Institute (2014), *Regional Mass Flow Model for Latin/South America*, IAI, London, available online at www.world-aluminium.org/publications/ (accessed April 2015).
24 *United Arab Emirates National Bureau of Statistics*, www.uaestatistics.gov.ae/ (accessed April 2015).
25 *The Skyscraper Center: The Global Tall Building Database of the Council on Tall Buildings and Urban Habitat*, www.skyscrapercenter.com/ (accessed January 2015).
26 M. Patterson, A. Martinez, J. Vaglio and D. Noble (2012), *New skins for skyscrapers: anticipating façade retrofit*, in A. Wood, T. Johnson and Q. Li (eds), *Asia Ascending: Age of the Sustainable Skyscraper City*, CTBUH, Chicago, IL, pp. 209–215.
27 International Aluminium Institute (2014), *Regional Mass Flow Model for the Middle East*, IAI, London, available online at www.world-aluminium.org/publications/ (accessed April 2015).
28 M. Stacey (ed.) (2014), *Aluminium and Durability: Towards Sustainable Cities*, Cwningen Press, Llundain, pp. 49–80.
29 See, for example: Preservation Green Lab for the National Trust for Historic Preservation (2011), *The Greenest Building: Quantifying the Value of Building Reuse*, NTHP, Washington, DC, available online at www.preservationnation.org/information-center/sustainable-communities/green-lab/lca/The_Greenest_Building_lowres.pdf (accessed February 2015).
30 Pacific Northwest National Laboratory for the US Department of Energy (2010), cited in ibid., p. 92.
31 Ibid., p. 39.
32 Athena Sustainable Materials Institute (2014), *Athena Guide to Whole-Building LCAs in Green Building Programs*, Athena Sustainable Materials Institute, Ottawa, ON, available online at www.athenasmi.org/wp-content/uploads/2014/03/Athena_Guide_to_Whole-Building_LCA_in_Green_Building_Programs_March-2014.pdf (accessed April 2015).
33 U. M. J. Boin and J. A. van Houwelingen (2004), *Collection of Aluminium from Buildings in Europe: A Study by Delft University of Technology*, EAA, Brussels, available online at recycling.world-aluminium.org/uploads/media/_TUDelftBrochure2004.pdf (accessed April 2015).
34 International Council of Shopping Centers, *Global Shopping Center Directory*, available online at www.icsc.org/directories/global-shopping-center-directory (accessed March 2015).
35 International Aluminium Institute (2014), *Regional Mass Flow Model for North America*, IAI, London, available online at www.world-aluminium.org/publications/ (accessed April 2015).
36 *The Skyscraper Center: The Global Tall Building Database of the Council on Tall Buildings and Urban Habitat [CTBUH]*, www.skyscrapercenter.com/ (accessed January 2015).
37 International Aluminium Institute (2014), *Regional Mass Flow Model for Other Asia*, IAI, London, available online at www.world-aluminium.org/publications/ (accessed April 2015).
38 *The Skyscraper Center: The Global Tall Building Database of the Council on Tall Buildings and Urban Habitat*, www.skyscrapercenter.com/ (accessed January 2015).
39 U. M. J. Boin and J. A. van Houwelingen (2004), *Collection of Aluminium from Buildings in Europe: A Study by Delft University of Technology*, EAA, Brussels, available online at recycling.world-aluminium.org/uploads/media/_TUDelftBrochure2004.pdf (accessed April 2015).
40 M. Hu, H. Bergsdal, E. van der Voet, G. Huppes and D. B. Müller (2010), *Dynamics of urban and rural housing stocks in China*, Building Research & Information, 38(3), p. 309.

cast aluminium components

Cast Aluminium Components

The casting of metals typically uses recycled material combined with a relatively small percentage of primary material to balance the alloy so as to achieve the specified performance criteria. Cast aluminium components are a very clear demonstration of the almost infinite recyclability of aluminium. Although construction is not currently a major user of cast aluminium components – unlike, for instance, the automotive industry, in which cast aluminium is used for the engine blocks of contemporary cars – there are many examples of the use of cast aluminium in high-quality architecture from the past 85 years.

Why Use Cast Metal Components for Architecture and Infrastucture?

The advantages of casting can be summarised as follows:

- **Form** – structural and geometrical requirements can be accommodated in a single component;
- **Economical use of material** – casting puts the metal where it is required, meaning the sections can be tailored to meet the specific design loads;
- **Ease of production** – once the form and mould or die is established with appropriate quality assurance, reliable components can be readily and repeatedly manufactured;
- **Durability** – casting produces low-maintenance components;
- **High quality of finish** – this is dependent on the type of casting method; for example, lost-wax casting provides very fine finishes;
- **Fine tolerances** – this is also dependent on casting method.[1]

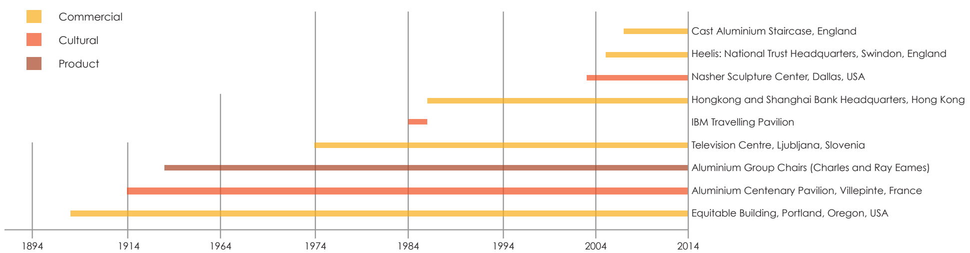


Fig 6.1 Graph showing cast aluminium component case studies featured within this chapter

Case Studies

Fig 6.2 The Equitable Building, Portland, Oregon, designed by Pietro Belluschi, incorporates cast aluminium cladding panels

The strong potential for the use of cast aluminium components in architecture is demonstrated by the case studies considered in this chapter. In *Aluminium and Durability*, Chapter Three *Aluminium Pioneers* illustrates the inter-war use of decorative cast aluminium components including the cast aluminium spandrel panels of the Empire State Building in New York, completed in 1931, and the cast aluminium lamps of the US Customs House in Philadelphia, completed in 1933.[2] Even with the extensive use of digital modelling and the exploration of three-dimensional form in contemporary architecture, it would be surprising to see a revival of decorative cast aluminium components in twenty-first-century construction. However, there is a strong need for solar shading to reduce heat loads and energy demands, whilst generating comfort, and buildings with low carbon footprints. Aluminium is an excellent material choice for solar shading as it is robust, formable and durable. Cast aluminium can be used without coating, as shown by Heelis, the National Trust Headquarters, or it can be PVDF coated, as specified for the the Hongkong and Shanghai Banking Corporation Headquarters. Another option is polyester powder coating, as used on the Nasher Sculpture Center.

Located in Portland, Oregon, the **Equitable Building**, now known as the Commonwealth Building, was designed by Pietro Belluschi and completed in 1948. The headquarters of the Equitable Savings & Loan Association, it was based on his '194X' competition design for an office building overtly inspired by aircraft technology. The building has aluminium doubleglazed curtain walling and cast aluminium cladding. Originally, Belluschi wanted to use an all-aluminium composite panel with a honeycomb core. The completed project uses cast aluminium panels, which are 4.75mm (3/16") thick.

The case study on the 1954 **Aluminium Centenary Pavilion** by Jean Prouvé in Chapter Three of this report illustrates the early use of cast aluminium structural components, which were highly integrated into the overall assembly.

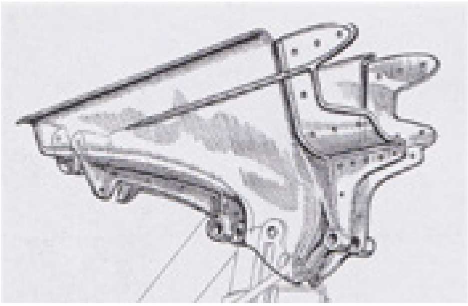


Fig 6.3 Drawing of cast aluminium component by Jean Prouvé

Fig 6.4 The Aluminium Centenary Pavilion, designed by Jean Prouvé

The **Aluminum Group chairs**, designed by Charles and Ray Eames and launched in 1958, were based on some of the most elegant cast aluminium components in architectural interiors.[3] Vitra, the current licensed manufacturer of the designs of Charles and Ray Eames, use 95 per cent recycled aluminium to cast the components of the Aluminum Group chairs. Vitra, in its *Sustainability Report 2012*, observed that 'aluminium is an extremely durable material, which can be completely recycled at the end of its useful life'.[4] One of Vitra's primary goals, in terms of sustainability, is to 'make durable products with a long lifespan, both in terms of function and aesthetics'.[5]

Fig 6.5 Casting block of the Aluminum Group chair

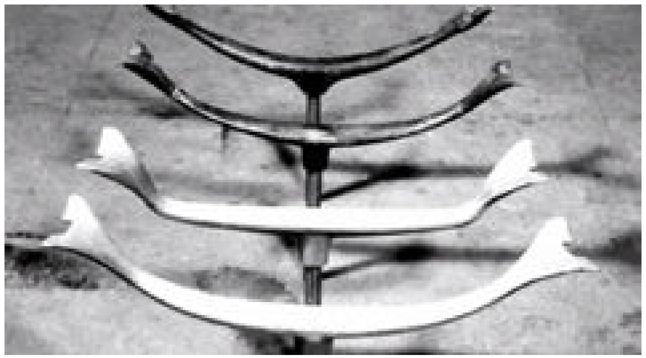


Fig 6.6 Early prototypes of the cast aluminum component of the Aluminum Group chair by Charles and Ray Eames

Fig 6.7 Aluminum Group chair designed by Charles and Ray Eames, 1958

The **Ljubljana Television Centre** in Slovenia is clad in cast aluminium panels. Completed in 1974, it was designed by architect France Rihtar in collaboration with Branko Krasevac, who designed the façades. He was involved in the design of almost all important aluminium façades in Slovenia, the northern part of the former Yugoslavia. The aluminium panels were cast horizontally so that the surface was marked with the form of the cooling material. This gives a visual effect that is comparable to stone.

Fig 6.8 The Ljubljana Television Centre, Slovenia, designed by architect France Rihtar in collaboration with Branko Krasevac

Fig 6.9 The Ljubljana Television Centre, Slovenia, used horizontally cast aluminium cladding panels in 1974

IBM Travelling Pavilion: Architect Renzo Piano, 1984–86

Renzo Piano designed the IBM Travelling Pavilion with the inventive engineer Peter Rice of Arup. The pavilion has a simple extruded form that is built up from twelve semi-circular arches of bespoke polycarbonate pyramids.[6] These are tied together by shapely timber sections of laminated larch and jointed with cast aluminium nodes, which are glued into the timber. The pavilion was explicitly detailed to be readily assembled and disassembled.

Peter Rice observed that Renzo Piano had 'defined [the project] by making a romantic prototype, which he photographed and showed to the client to demonstrate the central idea'.[7] He continued: 'Renzo had combined the timber with cast aluminium to emphasize the natural quality of the space. Polycarbonate as a material is light and robust but it is also not very strong: its loadcarrying capacity and its stiffness are low.'[8]

The pavilion took about three weeks to assemble on each site, having been delivered by 18 articulated lorries. Peter Buchanan records the design period as 1982 to 1984,[9] and Piano considered the core design time to be 'nine months and what resulted was an artificial typology so perfect that it evoked the rhythmical structure of nature'.[10] The purpose of the pavilion was to present the idea of having a personal computer at home as a 'natural' part of life.

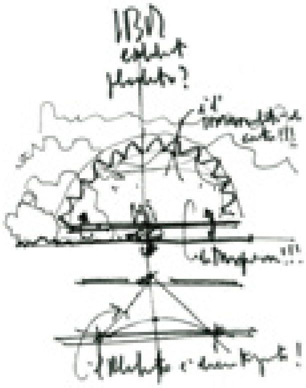
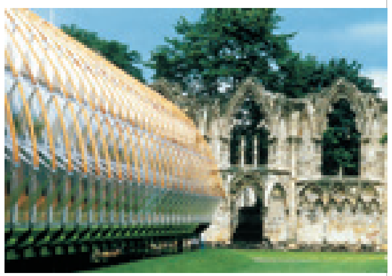


Fig 6.10 Sketch of the IBM Traveling Pavilion by Renzo Piano

Fig 6.11 Cast aluminium nodes linking shapely timber sections with the structural polycarbonate skin

Fig 6.12 The IBM Travelling Pavilion by Renzo Piano in York, England

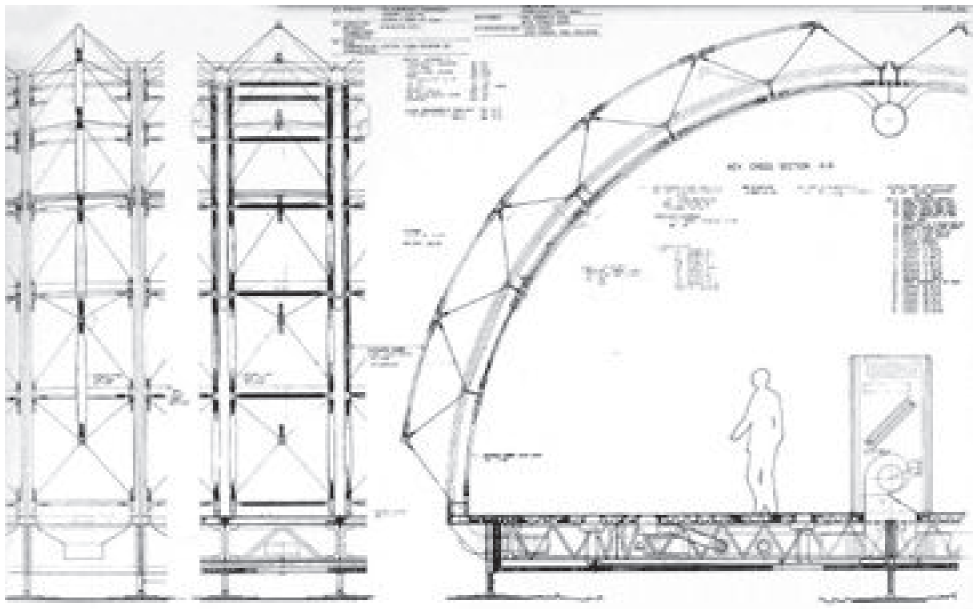


Between 1984 and 1986, the pavilion was erected in 20 cities across 14 European countries. At each location, Buchanan observes,

> a computer simulation was run of outside light and thermal conditions, taking account of the orientation of the pavilion, position of shading trees and so on. This determined the exact placing of opaque pyramidal elements, which were fixed within the transparent ones, and of the mesh screens. Together, these controlled glare and heat loads.[11]

Piano's carefully crafted assembly of components of the IBM Travelling Pavilion formed a construction system, yet in each location a site-specific work of architecture was created.[12] It has been suggested that Piano's use of cast aluminium in the IBM Travelling Pavilion was inspired by the elegant, lightweight, cast aluminium racing bicycle components produced in northern Italy by Campagnolo.[13]

Fig 6.13 Section and elevations of the IBM Travelling Pavilion by Renzo Piano Building Workshop



Hongkong and Shanghai Bank Headquarters: Architect Foster Associates, 1986

A case study of the Hongkong and Shanghai Bank Headquarters, designed by Foster Associates (now Foster + Partners) and completed in 1986, is included in Chapter Three of *Aluminium and Durability*.[14] Of specific relevance here is the use of diecast aluminium to produce the brise soleil of the curtain walling.

Die casting is appropriate for metals with a lower melting point than steel, including aluminium, as the metal is poured into a steel mould. The moulds are thus very expensive and this process is predominantly used to produce accurate machine parts. It is a high-speed, high-volume application of casting technology. A typical construction application is the treads of an escalator. This demonstrates the precision and complexity of form that can be achieved by using a die casting. However, the die costs are relatively high and therefore a repeat of 2,500 cast components from each die is typically necessary.

The cast brackets that support the brise soleil of the Hongkong and Shanghai Bank Headquarters are an exemplary use of an aluminium die casting, producing a finely engineered and dynamic component, which is a vital part of the architecture of the building. 4,000 brackets were needed for the complete façade, therefore a die casting was an eminently appropriate method of production.[15] These die-cast aluminium components were finished in PVDF, as was the curtain walling and rainscreen cladding of the building.

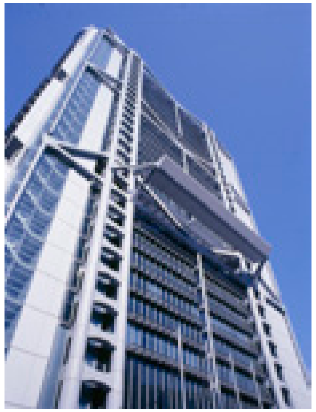


Fig 6.14 The Hongkong and Shanghai Bank Headquarters, architect Foster Associates

Fig 6.15 Brise soleil of the curtain walling of the Hongkong and Shanghai Bank Headquarters

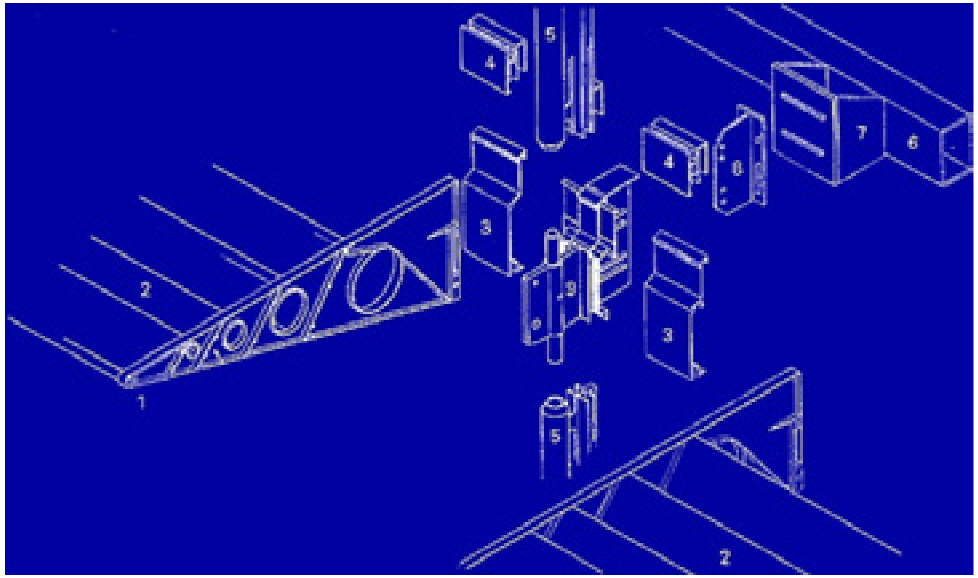


Fig 6.16 Exterior detail of the Hongkong and Shanghai Bank Headquarters showing the die-cast brise soleil

1. *Die-cast aluminium support bracket*
2. *Extruded aluminium fins*
3. *Extruded aluminium fascia*
4. *Extruded aluminium horizontal glazing channel*
5. *Mullion – extruded aluminium with cast aluminium conical end pieces*
6. *Perimeter steel RHS fixed back to slab*
7. *Steel bracket*
8. *Adjustable steel anchor tee*
9. *Cast and extruded aluminium fixing assembly with stainless steel spigot*

Nasher Sculpture Center: Architect Renzo Piano, 2003

Fig 6.17 Cast aluminium shells of the solar shading at the Nasher Sculpture Center, designed by Renzo Piano Building Workshop

The cast aluminium solar shading of the Nasher Sculpture Center, designed by Renzo Piano Building Workshop, is an exemplar of the combination of digital design and infinitely recyclable aluminium to temper the bright Texan sunshine, providing visual comfort whilst minimising energy consumption within this gallery. The Nasher Sculpture Center is one of the few institutions in the world devoted to the exhibition, study and preservation of modern sculpture. It consists of a 5,000m^2 building and a two-acre garden. From the outset, the project was conceptualised as a synthesis of nature and building. The building is made of parallel stone walls, which create the gallery pavilions. Each pavilion is enclosed by low-iron glass façades and a roof that permits a 150m long unobstructed corridor view from the street, through the building and across the length of the garden. These attenuated perspectives have created an effect of transparency and lightness.[16]

The cast aluminium shells form the unique shading of the Nasher Sculpture Center's bespoke glass roof. Each shell plays an important part in creating an environment with optimum conditions for displaying sculpture by successfully filtering direct light that could degrade the works on display. The result is a spectacular, naturally lit environment. The design team at Arup worked closely with architect Renzo Piano to deliver this matrix of daylight modifiers. The result is an eye-catching roof composed of over half a million aluminium shells. Each shell weighs a mere 40g and is precisely cast in aluminium at the correct angle to exclude the direct rays of the sun whilst maximising and precisely controlling daylight as the sun tracks across the Dallas sky. Shade is critical for a glazed-roof gallery in a place like Dallas, where the sun is so intense. The form for the roof shading was found by using equations to chart the sun's path through the course of the day. In-house rapid prototyping was used to produce a 1:1 prototype of the solar-shading cells, in wax.

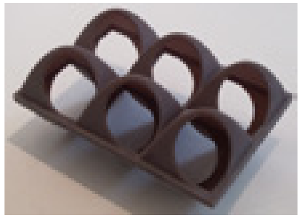


Fig 6.18 Wax prototype for the shells of the solar shading at the Nasher Sculpture Center

Fig 6.19 A gallery of the Nasher Sculpture Center bathed in daylight

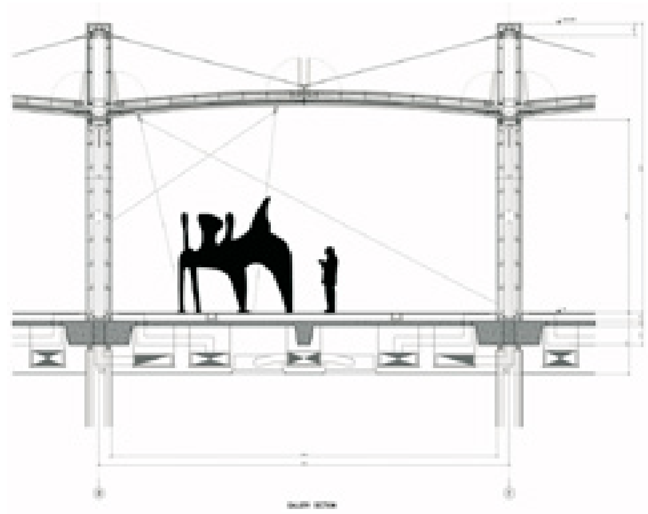


Fig 6.20 Section of the Nasher Sculpture Center

Alistair Guthrie, Arup Director noted:

> After projecting the sun's path specific to the gallery site, we then designed the shells and roof in a way that enabled Piano's ambition to create the thinnest possible roof. The design ensures that the gallery enjoys excellent daylight but excludes direct sunlight. What's unusual about this project is that the roof was cast in aluminium straight from the drawing board to production using original computer programming data.[17]

Heelis, National Trust Headquarters: Architect Feilden Clegg Bradley Studios, 2005

Designed by Feilden Clegg Bradley Studios, Heelis, the National Trust Headquarters, is an exemplar in office design, completed in 2005. It relocated and centralised four formerly separate offices under one roof, streamlining operations and reducing the National Trust's expenses and carbon footprint. Heelis has won a number of awards, including the 2006 RIBA Sustainability Award, and combines strong environmental consideration with design quality and user comfort. The building demonstrates that with high-quality design, improvements in sustainability can be achieved within institutional funding standards and budget.

The project was led by Jo Wright (Studio Leader), Peter Clegg (Senior Partner) and Matt Vaudin (Architect). Heelis' ethos of sustainability began with the choice of a brownfield site. The form of the building is sited in its context in Swindon, in Wiltshire, UK, responding to the existing railway sheds of the former Great Western Railway Works engineered by Isambard Kingdom Brunel. The pitched roofs are orientated north–south; whilst this contrasts with the existing railway sheds, it creates a south-facing, primary façade allowing for optimal thermal and light gains. The fifth, and arguably most important, façade includes a northfacing rooflighting system that creates an average internal daylight factor of over 5 per cent within the deep plan. Incorporated on the roof are photovoltaic panels; whilst shading the roof lights, these provide 35 per cent of the building's energy requirements.

Materials were sourced to ensure sustainability in production, use and demolition. UK-manufactured bricks, locally sourced timber, wool from Herdwick sheep and locally cast aluminium used for solar

6.21–6.22 Cast aluminium solar shading of Heelis

Fig 6.23 The industrial form of Heelis responds to the existing railway sheds of the former Great Western Railway Works

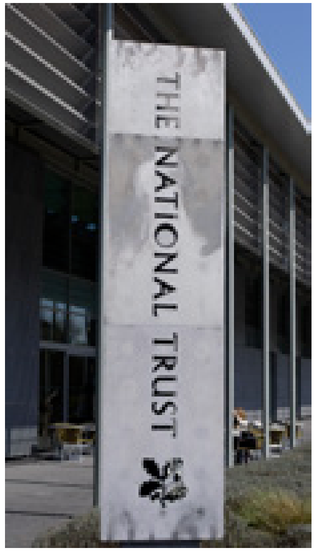


Fig 6.24 Heelis, the National Trust Headquarters, architect Feilden Clegg Bradley Studios

shading louvres contributed to the material palette. The louvres, cast at Novacast in Melksham, are made from an aluminium alloy that is approximately 92 per cent recycled, lowering the building's carbon footprint; producing recycled aluminium uses only 5 per cent of the energy needed to produce primary aluminium. The use of aluminium solar shading is an exemplar of an architectural use for cast aluminium scrap. The site and foundry are both in Wiltshire, and therefore the cast solar shading only travelled 27.7 component miles to be installed, thus minimising the transportation element of its embodied energy. Novacast produced 496 solar-shading panels for Heelis, with a total cast weight of 5,481kg. All of the aluminium content of these castings is recycled. The final recycled content is balanced by 8–10 per cent silicon, to achieve the chemical analysis required by British and European Standards for the specified alloy, LM6M.[18] Like all aluminium products, the solar shading of Heelis remains fully recyclable.

Aluminium is also used to form other components within this building, including a cast aluminium reception desk. The aluminium components are durable, reusable, relocatable and easily replaced, should this prove necessary due to mechanical damage. They can also be readily recycled should this building be no longer required in the future, which may be in over 120 years' time, noting that the National Trust was founded in 1895.

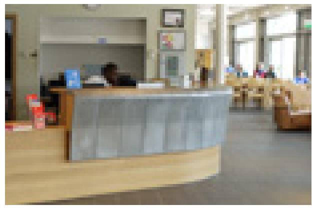


Fig 6.25 Cast aluminium reception desk of Heelis

Fig 6.26 Approaching the public entrance of Heelis

Cast Aluminium Staircase: Architect Julian Arendt, 2007

This cast aluminium staircase was designed by architect Julian Arendt, with engineer David Crookes of Fluid Structures, as part of a conversion of a listed building in England to a family home. The engineering practice, Fluid Structures, also took on the role of contractor, employing a supply chain of specialist sub-contactors. The stringers of the staircase were cast in LM6-grade aluminium by Barron-Clark Castings, a foundry in Peterborough that specialises in casting aluminium. The mould cost £12,000 and was, with careful detailing, used to cast all eight components of the staircase. Each component cost about £1,000 to cast. Lugs, to receive the staircase treads, were incorporated into the casting to minimise post finishing, see Figure 6.34. The castings only needed to be drilled to receive stainless-steel fixing bolts. The integration of detailing was undertaken using basic physical models. David Crookes has observed that next time 'we will draw the connection using Rhino Software and then have it rapid prototyped'.[19] Machining of the castings to receive fixings and assembling the staircase was undertaken by Mark Wilder of Silverton Fabrication. The castings were hand polished, revealing the curved profile.

Both the architect and engineer were delighted with this cast aluminium staircase and its 1950s car fenderlike visual quality. The cast aluminium staircase proved to be 25 per cent more costeffective when compared to a stainless-steel option.

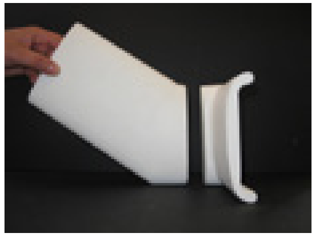


Fig 6.28 Prototype cast stringer connection detail

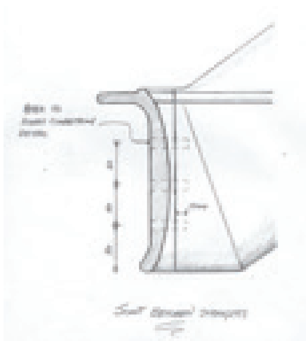


Fig 6.29 Stringer detail drawing

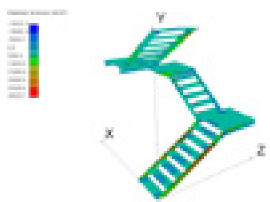


Fig 6.30 Digital model stress testing of staircase (kN/m²)

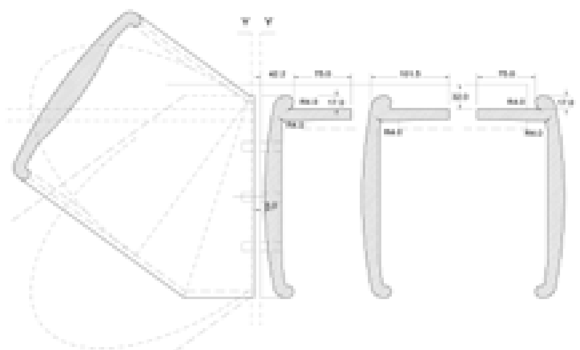


Fig 6.27 Detail drawing of cast aluminium stringer

Fig 6.31 [top right] Completed cast aluminium staircase designed by Julian Arendt with engineer David Crookes of Fluid Structures

Fig 6.32 [right] Cast aluminium staircase being fabricated for a family home in London

Fig 6.33 [far right] Completed staircase landing to stringer detail

Fig 6.34 Section through a pair of stringers, showing lug plates that support the timber treads

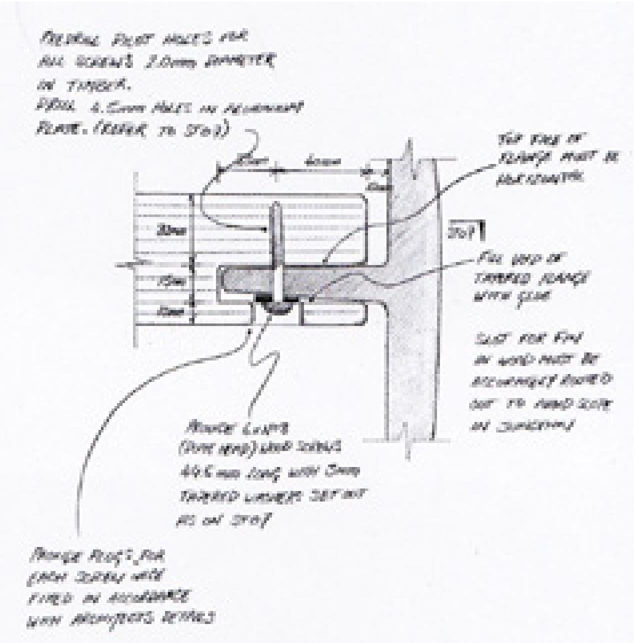


Fig 6.35 Connection detail showing fixing of timber tread to a stringer with hidden screws

Fig 6.36 Internal face of cast aluminium stringer showing connection flanges

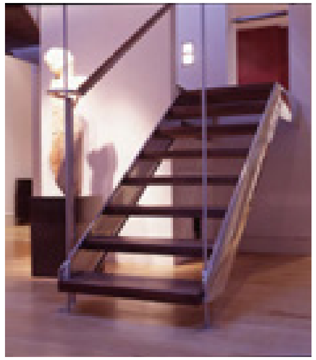


Fig 6.37 The staircase within a family home in London

Fig 6.38 Polished, cast aluminium staircase with timber treads

Notes

1 Updated from M. Stacey (2001), *Component Design*, Architectural Press, Oxford.
2 M. Stacey (ed.) (2014), *Aluminium and Durability: Towards Sustainable Cities*, Cwningen Press, Llundain, pp. 21–111.
3 Note the original American spelling of 'aluminium' has been retained. For more information on inventive designs by Charles and Ray Eames, see: D. Murphy (ed.) (1997), *The Work of Charles and Ray Eames: A Legacy of Invention*, Abrams, New York.
4 Vitra (2012), *Sustainability Report 2012*, Vitra, Birsfelden, p. 8, available online at www.vitra.com/en-gb/corporation/sustainability (accessed December 2013).
5 Ibid., p. 7.
6 M. Stacey (2012), *Digital Craft in the Making of Architecture*, in B. Sheil (ed.), *Manufacturing the Bespoke: Making and Prototyping Architecture*, Wiley, Chichester, pp. 60–62.
7 P. Rice (1994), *An Engineer Imagines*, Artemis, London, p. 107.
8 Ibid.
9 P. Buchanan (1993), *Renzo Piano Building Workshop: Complete Works: Volume 1*, Phaidon, London, p. 110.
10 M. Dini (1984), *Renzo Piano: Projects and Buildings 1964–1983*, Electra/Rizzoli, New York, p. 74.
11 P. Buchanan (1993), *Renzo Piano Building Workshop: Complete Works: Volume 1*, Phaidon, London, p. 112.
12 Peter Buchanan records that many contemporary critics observed that Renzo Piano's buildings 'were mere assemblies [of components] rather than *real* architecture'. Ibid., p. 113, emphasis in original.
13 *Campagnolo*, www.campagnolo.com/jsp/en/index/index.jsp (accessed February 2015).
14 M. Stacey (ed.) (2014), *Aluminium and Durability: Towards Sustainable Cities*, Cwningen Press, Llundain, pp. 100–103.
15 M. Stacey (2001), *Component Design*, Architectural Press, Oxford, pp. 76–77.
16 M. Stacey (2013), *Prototyping Architecture*, Riverside Architectural Press, Cambridge, ON, pp. 200–203. See also: The Future Builds with Aluminium, *Nasher Sculpture Center*, available online at http://greenbuilding.world-aluminium.org/en/benefits/sympathetic/nasher-sculpture-center.html (accessed April 2015).
17 Ibid.
18 Data on casting mix supplied directly by Novacast by email to the author, April 2014.
19 D. Crookes (2011), *Fluid Structures: Adventures in Engineering*, Watermark Publications, Brighton, p. 28.

SEVEN

interim conclusion

Interim Conclusion

The Towards Sustainable Cities Research Team recommends that studies of aluminium collection and recovery rates should be conducted at a regional scale, modelled on the 2004 TU Delft study *Collection of Aluminium from Buildings in Europe*.[1] This research should include, where possible, the age of the building at the time of demolition, as well as the collection rate. Collating Site Waste Management Plans [SWMPs] may form a viable alternative to establish this data.

The twenty-first century will see an increasing number of buildings designed for disassembly [DfD] with fully reversible details that facilitate change during the projects' lifetimes, and that also facilitate relocation and reuse or disassembly and recycling. Currently, this appears to be prompted more by voluntary demolition protocols, environmental assessment tools, environmental awareness and Building Information Modelling [BIM] than by regulation. To facilitate the retrofit of windows and curtain walling, there is also a need for DfD within building envelope systems.

Aluminium has an important role in improving building performance and reducing the demolition of existing building stock, through over-cladding, reglazing and deep retrofit. Aluminium also has a significant role in the reglazing of listed buildings where the sightlines of the glazing are of vital importance.

Specifiers, both architects and engineers, need reliable and transparent information on the potential materials used in the delivery of architecture and infrastructure. The need to understand the full range of impacts of material selection as a holistic system is leading to an increased use of Life Cycle Assessment [LCA]. The aluminium industry is an early adopter of LCA, based on reliable and transparent information.

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 recovery of aluminium is primarily driven by the value of the metal, including its ability to be recycled without loss of properties with a much lower energy input and environmental impact than primary aluminium production. The review of short-life architecture case studies in Chapter Four reveals that reuse is often preferred to recycling.

Although Stewart Brand's timescales for change within architecture are too short, as discussed in the first report in the Towards Sustainable Cities Research Programme *Aluminium and Durability*, his concept of layers of change remain valid.[2] On demolition, aluminium can be found in buildings not originally built of aluminium.[3] There is a need for further research on the life expectancy of buildings and infrastructure. This should encompass the full cycle of components and systems that may need to be replaced during the life of a building.

Aluminium and Durability recommended that the service life of aluminium windows should be revised upwards from 40 years to at least 80 years. This should be used to inform environmental product declarations [EPDs]. The service life of curtain walling also needs to be studied, including all of the component parts. The evidence in this research suggests that both aluminium windows and aluminium curtain walling are being replaced on longer cycles than many expect. To summarise key findings from Chapter Two, the average age of major North American projects studied in this research upon reglazing is over 60 years. Using the beta version of the database in *facaderetrofit.org*, the average age of buildings at the time of curtain-walling retrofit is almost 40 years, with projects in Peru, Norway, North America and the UK. For reinvention and overcladding, the average age of the buildings is over 70 years, with projects mainly in North America though with some examples from Norway and Germany. Interestingly, this research establishes an average age of buildings for window replacement of over 70 years.

The worldwide construction of skyscrapers over 150m high will probably lead to longer life expectancies, as only seven projects of this height have ever been demolished. Patterson and colleagues recommend that tall buildings should have a structural life expectancy of at least 100 years.[4] Hu and colleagues suggest that because of the land lease period in China and the provision of housing at market prices since 1978, the life expectancy of urban housing in China could become 75 years.[5]

Chapter Five considers the potential availability of aluminium scrap from architecture and infrastructure in the future. The sensitivity analysis in this chapter suggests that life expectancy is the most significant variable in terms of potential release of aluminium to recycling. Although this chapter focuses on aluminium scrap arising from the retrofit and demolition of architecture and infrastructure, it is important to emphasise the performative role of the 775 million tonnes of aluminium still in use in 2012 and accumulated since 1888.

Chapter Six reveals that cast aluminium components play a significant role in contemporary architecture, with widespread adoption. Aluminium is an excellent material choice for solar shading as it is robust, formable and durable, with casting a preferred mode of manufacturing. Quantifying the environmental benefit of aluminium solar shading forms part of the further scope of the Towards Sustainable Cities Research Programme. Cast aluminium components have an as-yet underexplored role as a structural component within building structures.

Notes

1 U. M. J. Boin and J. A. van Houwelingen (2004), *Collection of Aluminium from Buildings in Europe: A Study by Delft University of Technology*, EAA, Brussels, available online at http://recycling.world-aluminium.org/uploads/media/_TUDelftBrochure2004.pdf (accessed April 2015).

2 S. Brand (1994) *How Buildings Learn: What Happens to Them After They're Built*, Viking, New York, pp. 12–13, cited by M. Stacey (ed.) (2014), *Aluminium and Durability: Towards Sustainable Cities*, Cwningen Press, Llundain, pp. 272–273.

3 U. M. J. Boin and J. A. van Houwelingen (2004), *Collection of Aluminium from Buildings in Europe: A Study by Delft University of Technology*, EAA, Brussels, available online at http://recycling.world-aluminium.org/uploads/media/_TUDelftBrochure2004.pdf (accessed April 2015).

4 M. Patterson, A. Martinez, J. Vaglio and D. Noble (2012), *New skins for skyscrapers: anticipating façade retrofit,* in A. Wood, T. Johnson and Q. Li (eds), *Asia Ascending: Age of the Sustainable Skyscraper City*, CTBUH, Chicago, IL, pp. 209–215.

5 M. Hu, H. Bergsdal, E. van der Voet, G. Huppes and D. B. Müller (2010), *Dynamics of urban and rural housing stocks in China*, Building Research & Information, 38(3), pp. 301–317.

glossary

Glossary

This glossary has been arranged in the following stages: Production, Design, and Life Cycle Methodology concluding with Construction, Use and Disassembly, in line with the life cycle of buildings and infrastructure. It is organised alphabetically within each section, except when the logic of reading specific expressions is necessary. Unless stated otherwise, definitions in this glossary have been based on *The Concise Oxford English Dictionary*, tenth edition with addenda, Oxford University Press, Oxford 2002.

Production

Bayer process: the most commonly utilised industrial process for extracting alumina from bauxite ores.

Electrolysis: the use of a direct electrical current [DC] to produce an otherwise nonspontaneous chemical reaction. In the production of aluminium from alumina, electrolysis is a key part of the Hall–Héroult process. For more detail, see below.

Energy mix: the combination of energy resources required to produce a material, product or service. In the case of primary aluminium, the majority of the energy requirement is in the form of electricity, which has been generated from a mix of primary energy sources (thermal, hydropower, etc), but energy is also transferred through the combustion of fuels (coal, gas, etc). Energy mixes, combining power and fuel mixes, are often regionally defined, based on the availability of energy resources.

Grid mix: is a description of the makeup and efficiency of electricity and heat transfer through a larger energy transmission system. In accordance with ISO 14044, in Life Cycle Assessment, when modelling electrical consumption, account shall be taken of the fuel mix and the efficiencies and losses associated with fuel combustion, conversion, transmission and distribution. Average grid mixes account for the temporal and spatial variability of grid efficiencies across a region, country or industry.[1]

Hall–Héroult process: an electrolytic process for the reduction of alumina into liquid aluminium. It is the most commonly utilised industrial method of primary aluminium production.

Power mix: is the specific mix of electricity generation energy resources such as: hydro, nuclear or thermal (coal, oil and gas).

Primary energy: an energy form found in nature that has not been subjected to any conversion or transformation process. It is energy contained in raw fuels, and other forms of energy received as input to a system. Primary energy can be nonrenewable or renewable.

Design

Building Information Modelling [BIM]: a holistic approach to the design of architecture and infrastructure, based on the shared use of three-dimensional digital models. Building Information Models include data on materials, scheduling and performance, among other categories, for the purpose of design, visualisation, simulations, and structural and environmental analysis.[2]

Design for Disassembly (or **Design for Deconstruction**) **[DfD]**: a principle applied during the design process that results in the detailing of reversible joints, connections and attachment mechanisms between building materials and components, thus enabling future reconfiguration, relocation, reuse and recycling.[3]

Lightweighting: the process of removing mass from a design, such as a car, whilst maintaining (or improving) all other functional performance criteria.

Recyclability: the quality of a product or material that all or part of its value can be recovered at the end of its useful life with minimal loss or change of quality.

Life Cycle Methodology

Embodied energy (also known as **cumulative energy use**): the sum of all energy consumed in the production of materials, goods or services including extraction, manufacturing and fabrication, often described through embodied energy assessments. **Recurring embodied energy**: energy needed over time to maintain, repair or replace materials, components or systems during the life of a building.

Life Cycle Assessment [LCA]: an approach to quantifying the environmental impacts of a product or service across its life cycle.

Cradle-to-grave Life Cycle Assessment [LCA]: considers all the aspects of a product's life cycle (i.e. raw material extraction and processing, manufacture, transportation, use, repair and maintenance, and reuse, disposal or recycling).

Cradle-to-gate Life Cycle Assessment [LCA]: an alternative LCA scope that focuses on the environmental impacts associated with material extraction, manufacturing, transportation, construction or assembly. For building products this scope is often used to represent materials at point of sale, when they are more easily compared and delineated, as well as when use and endoflife processes are uncertain. However, cradletogate assessments do not capture the full environmental impacts of goods or service and are not permitted for life cycle comparisons between materials or products (see ISO 14044)[4].

End-of-life recycling method: a methodology for the treatment of recycling in LCA that is based on a product life cycle and material stewardship perspective. It considers the fate of products after their use stage and the resultant material output flows.[5]

Recycled content method: a methodology for the treatment of recycling in LCA that looks back to where a material was sourced, and provides a measure of waste diversion. This approach is based on a waste management perspective, where the general aim is to promote a market for recycled materials that is otherwise limited, uneconomic or underdeveloped.[6]

Construction, Use and Disassembly

Bricolage: the construction a building from a diverse range of materials and components previously used in earlier buildings.

Deconstruction: the dismantling of a building in such a manner that its component parts can be collected, sorted and reused or recycled.

Deep retrofit, also known as **deep energy retrofit** (both terms originate in North America): the process of conducting whole-building analysis and construction measures that aim to increase the energy efficiency and performance of an existing building. Deep retrofits typically result in at least a 30 per cent reduction in operational energy requirements (see below).

Demolition: the action or process of pulling or knocking down a building.

Life expectancy: the anticipated period of time that a building or infrastructure can be expected to last with appropriate periodic maintenance. This is typically used at the briefing stage of a project as an operative design criterion. The guarantees or warranties provided during a building contract, which often include caveats such as annual inspections and cleaning, are not the same as the life expectancy of a material or product and can be underwritten by third-party insurers.

New Build Recovery Index [NBRI]: the percentage by area (m^2) of materials reused in a new building. It forms part of the ICE Demolition Protocol 2008.[7]

Operational energy: the energy required to provide a comfortable and productive internal building environment. This includes the energy required to heat, cool and provide electrical services such as artificial lighting to a building during its use. **Energy efficiency measures [EEM]** (or **energy conservation measures [ECM]**): measures implemented to reduce energy consumption in a building. These may include changes to technologies or human behaviour.

Over-cladding: the process of placing insulation and a new durable skin over an existing building without removing the existing building fabric, to improve the thermal performance of the building whilst also addressing other issues such as water ingress or interstitial condensation, air infiltration and appearance.

Reclamation: the process of setting aside material from the waste stream for future reuse with minimal processing.

Recycling: the process of recovering valuable materials or resources from products at the end of their useful life, from waste streams or from production processes.

Refurbishment: the process of renovating and redecorating a building.

Reinvention of architecture: a process that goes beyond repair, renovation and refurbishment. It involves the recasting of the architecture on a holistic basis encompassing aesthetic and performative criteria, including operating energy, and can be related to the term deep retrofit, see above.

Remanufacturing: the process of returning a product to its original performance specification.

Renovation: the process of restoring something old to a good state of repair.

Reuse: the process of using something again or more than once. Often the reuse of a building will involve the introduction of a new programme of use – for example, changing the use from office to residential. The reuse of components will typically involve the same function but in a new assembly. Reuse can also refer to the use of reclaimed materials for their original purpose.

Retrofit: the process of fitting a component not fitted during manufacture or original construction process. This term is now widely applied when a building is extensively repaired and upgraded. This may or may not include a change of use.

Notes

1 I International Organization for Standardization (2006), *ISO 14040:2006 Environmental Management: Life Cycle Assessment – Principles and Framework*, second edition, ISO, Geneva

2 BIM definition based on US National BIM Standard – US Version 2 (an initiative of our National Institute of Building Sciences).

3 B. Guy and N. Ciarimboli, *DfD: Design for Disassembly in the Built Environment: A Guide to Closed-Loop Design and Building*, City of Seattle, King County, WA, pp.3–4, available online at www.lifecyclebuilding.org/docs/DfDseattle.pdf (accessed April 2015). This digital publication acknowledges C. Morgan and F. Stevenson (2005), *Design and Detailing for Deconstruction*, SEDA Design Guides for Scotland, Issue 1, Glasgow, p. 4, available online at www.seda.uk.net/assets/files/guides/dfd.pdf (accessed November 2014) for extensive use of adapted excerpts.

4 International Organization for Standardization (2006), *ISO 14040:2006 Environmental Management: Life Cycle Assessment – Principles and Framework*, second edition, ISO, Geneva.

5 J. Atherton (2007), *Declaration of the metals industry on recycling principles*, The International Journal of Life Cycle Assessment, 12(1), pp. 59–60.

6 Ibid.

7 Institution of Civil Engineers (2008), *Demolition Protocol 2008*, ICE, London, available online at www.ice.org.uk/Information-resources/Document-Library/Demolition-Protocol-2008 (accessed December 2014).

bibliography

Bibliography

Addis, B. (2007), *Building: 3,000 Years of Design, Engineering and Construction*, Phaidon, London

Advisory Council on Historic Preservation (1979), *Assessing the Energy Conservation Benefits of Historic Preservation: Methods and Examples*, Washington, DC, available online at www.achp.gov/1979%20-%20Energy%20Conserv%20and%20Hist%20Pres.pdf (accessed February 2015)

Allaway, D. (2008), *Materials Management, Climate, and Waste: Making the Connections*, West Coast Forum on Climate Change, Waste Prevention, Recovery and Disposal, Oregon Department of Environmental Quality, 26 June (American spelling of aluminum)

Allford Hall Monaghan Morris, *Angel Building*, available online at www.ahmm.co.uk/projectDetails/61/Angel-Building?sub=description (accessed January 2014)

Aluminium for Future Generations, *Global Metal Flow*, available online at http://recycling.world-aluminium.org/en/review/global-metal-flow.html (accessed March 2014)

Aluminium for Future Generations, *Refining Process*, available online at http://bauxite.world-aluminium.org/refining/process.html (accessed April 2015)

American Architectural Manufacturers Association Aluminum Material Council, *The Aluminum Advantage*, AAMA Aluminum Material Council, Schaumburg, IL, available online at www.aamanet.org/upload/file/AMC_Course.pdf (accessed December 2013)

Ando, T. (1995), *The Eternal within the Moment*, in dal Co, F. (ed.), *Tadao Ando: Complete Works (1969–1994)*, Phaidon, London, pp. 474–475

Architonic, *UK Pavilion, Shanghai World Expo*, available online at www.architonic.com/aisht/uk-pavilion-shanghai-world-expo-heatherwick-studio/5100437 (accessed January 2013)

Arsenault, P. J. (2013), *More than one way to skin a building,* Architectural Record, May, available online at http://continuingeducation.construction.com/article.php?L=352&C=1090 (accessed February 2015)

Athena Sustainable Materials Institute (2014), *Athena Guide to Whole-Building LCAs in Green Building Programs*, Athena Sustainable Materials Institute, Ottawa, ON, available online at www.athenasmi.org/wp-content/uploads/2014/03/Athena_Guide_to_Whole-Building_LCA_in_Green_Building_Programs_March-2014.pdf (accessed April 2015)

Atherton, J. (2007), *Declaration of the Metals Industry on Recycling Principles*, The International Journal of Life Cycle Assessment, 12(1), pp. 59–60

Bayliss, C. (2013), *International Energy Agency [IEA] Global Industry Dialogue & Expert Review Workshop: Aluminium Sector*, IEA, 7 October, available at www.iea.org/media/workshops/2013/industry/Session1_Aluminium_IAI_IEA_7Oct2013Workshop.pdf (accessed April 2015)

Boardman, B., Darby, S., Killip, G., Hinnells, M., Jardine, C. N., Palmer, J. and Sinden, G. (2005), *40% House*, Environmental Change Institute, Oxford, available online at www.eci.ox.ac.uk/research/energy/downloads/40house/40house.pdf (accessed February 2015)

Boin, U. M. J. and van Houwelingen, J. A. (2004), *Collection of Aluminium from Buildings in Europe: A Study by Delft University of Technology*, EAA, Brussels, available online at http://recycling.world-aluminium.org/uploads/media/_TUDelftBrochure2004.pdf (accessed April 2015)

Boothroyd, G. and Alting, L. (1992), *Design for Assembly and Disassembly*, CIRP Annals – Manufacturing Technology, 41(2), pp. 625–636

Bribian, I. Z., Aranda Usón, A. and Scarpellini, S. (2009), *Life cycle assessment in buildings: state-of-the-art and simplified LCA methodology as a complement for building certification*, Building and Environment, 44(12), pp. 2510–2520

Brookes, A. J. and Grech, C. (1990), *The Building Envelope*, Butterworth Architecture, Oxford

Brookes, A. J. and Grech, C. (1992), *Connections*, Butterworth Architecture, Oxford

Brundtland, G. H. (1987), *Our Common Future: Report of the World Commission on Environment and Development,* United Nations, New York, available online at www.un-documents.net/our-common-future.pdf (accessed April 2015)

Bryson, B. (2006), *The Life and Times of the Thunderbolt Kid*, Doubleday, New York

Buchanan, P. (1993), *Renzo Piano Building Workshop: Complete Works: Volume 1*, Phaidon, London

Carlisle, S., Friedlander, E., and Faircloth, B. (2015), *Aluminium and Life Cycle Thinking*, Cwningen Press, Llundain

CDM with Cascadia and R. W. Beck, Inc. (2010), *Chicago, Waste Diversion Study*, Chicago Department of Environment, Chicago, IL, available online at www.cityofchicago.org/dam/city/depts/doe/general/RecyclingAndWasteMgmt_PDFs/WasteAndDiversionStudy/WasteDiversionStudyReport2.pdf (accessed April 2015)

Chetwoods Architects, *Sainsbury's Millennium Store, Greenwich*, available online at http://chetwoods.com/portfolio/sainsburys-millennium-eco-store-greenwich/ (accessed January 2015)

Commonwealth of Massachusetts Executive Office of Energy and Environmental Affairs (2013), *Massachusetts 2010–2020 Solid Waste Master Plan: Pathway to Zero Waste*, Commonwealth of Massachusetts, Boston, MA, available online at www.mass.gov/eea/docs/dep/recycle/priorities/swmp13f.pdf (accessed April 2015)

Concise Oxford English Dictionary (2002), tenth edition, with addenda, Oxford University Press, Oxford

Crafts, N. (1997), *Britain's Relative Economic Decline 1870–1995*, Social Market Foundation, London

Crawford, R. H. (2011), *Life Cycle Assessment in the Built Environment*, Routledge, London

Crookes, D. (2011), *Fluid Structure: Adventures in Engineering*, Watermark Publications, Brighton

Cruickshank, D. (1995), *The Dome of Discovery*, Architectural Review, 197(1175), pp. 80–85, available online at www.packer34.freeserve.co.uk/dome.htm (accessed February 2015)

Culture Communication France (1993), *Supplementary Inventory of Historical Monuments*, February, available online at www.culturecommunication.gouv.fr/Politiques-ministerielles/Monuments-historiques/Intervenir-sur-un-monument-historique/Les-immeubles-inscrits-au-titre-des-monuments-historiques (accessed March 2015)

Das, S. K., Green, J. A. S. and Kaufman, J. G. (2010), *Aluminum recycling: economic and environmental benefits*, Light Metal Age, February, pp. 22–24, available online at www.phinix.net/services/Recycling/Aluminum_Recycling_Economic.pdf (accessed February 2015)

Departamento de Estadísticas e Información de Salud, *Estadísticas población*, available online at www.deis.cl/estadisticas-poblacion/ (accessed March 2015)

Department for Business Innovation & Skills/Government Office for Science (2013), *Future of Manufacturing: A New Era of Opportunity and Challenge for the UK – Summary Report*, The Stationery Office, London, available online at www.gov.uk/government/publications/future-of-manufacturing/future-of-manufacturing-a-new-era-of-opportunity-and-challenge-for-the-uk-summary-report (accessed April 2015)

Desai, A. and Mital, A. (2003), *Evaluation of disassemblability to enable design for disassembly in mass production*, International Journal of Industrial Ergonomics, 32(4), pp. 265–281

Dezeen (2010), *UK Pavilion at Shanghai Expo 2010 by Thomas Heatherwick*, 31 March, available online at www.dezeen.com/2010/03/31/uk-pavilion-at-shanghai-expo-2010-by-thomas-heatherwick-2/ (accessed February 2015)

Dini, M. (1984), *Renzo Piano: Projects and Buildings 1964–1983*, Electra/Rizzoli, New York

Dunlop, R. (2013), *Sainsbury's, Bugsby's Way, Greenwich Peninsula*, The Rubble Club, 29 November, available online at www.therubbleclub.com/2013/11/sainsbury's-bugsby's-way-greenwich-peninsula/ (accessed January 2015)

European Aluminium Association (2013), *Environmental Profile Report for the European Aluminium Industry*, EAA, Brussels, available online at www.alueurope.eu/wp-content/uploads/2011/10/Environmental-Profile-Report-for-the-European-Aluminium-Industry-April-2013.pdf (accessed April 2015)

European Aluminium Association (2015), *European Aluminium Industry's Sustainability Roadmap to 2025*, EAA, Brussels, p. 11, www.alueurope.eu/#3rdPage (accessed April 2015)

European Aluminium Association, *EU Primary aluminium import dependency*, available online at www.alueurope.eu/production-eu-primary-aluminium-supply/ (accessed April 2015)

European Aluminium Association/Organisation of European Aluminium Refiners and Remelters Recycling Division (2006), *Aluminium Recycling in Europe: The Road to High Quality Products*, Brussels, available online at http://recycling.world-aluminium.org/uploads/media/fl0000217.pdf (accessed April 2014)

Finnimore, B. (1985), *The A.I.R.O.H. house: industrial diversification and building state policy*, Construction History, 1, pp. 60–71

Front Row (2011) BBC Radio 4, 8 March, available online at www.bbc.co.uk/programmes/b00z6dvq (accessed December 2013)

The Future Builds with Aluminium, *Ballingdon Bridge*, available online at http://greenbuilding.world-aluminium.org/benefits/light-strong/ballingdon-bridge.html (accessed April 2015)

The Future Builds with Aluminium, *Nasher Sculpture Center*, available online at http://greenbuilding.world-aluminium.org/en/benefits/sympathetic/nasher-sculpture-center.html (accessed April 2015)

Golden, C. (2009), *Aluminium Recycling: An International Review* (thesis), Imperial College London, available online at http://warrr.org/785/1/13.27_IC_C_Golden_Masters_Thesis_2009.pdf (accessed February 2015)

Graf, O. A. (1985), *Otto Wagner: Das Werk des Architekten*, Böhlau Verlag, Vienna/Cologne/Graz

Green Building Information Gateway, *Credits*, available online at www.gbig.org/credits/7505 (accessed September 2014)

Gregory, R. (2009), *Serpentine Pavilion by SANAA, Serpentine Gallery, Hyde Park, London, UK*, Architectural Review, 1 August, available online at www.architectural-review.com/serpentine-pavilion-by-sanaa-serpentine-gallery-hyde-park-london-uk/8601012.article (accessed December 2013)

Guy, B. and Ciarimboli, N., *DfD: Design for Disassembly in the Built Environment: A Guide to Closed-Loop Design and Building*, City of Seattle, King County, WA, available online at www.lifecyclebuilding.org/docs/DfDseattle.pdf (accessed April 2015)

Hammond, G. and Jones, C. (Lowrie, F. and Tse, P. (eds.)) (2011), *Embodied Carbon: The Inventory of Carbon and Energy [ICE]*, BSRIA/Bath University, Bath

Harvard Green Campus Initiative (2006), *46 Blackstone Renovation Case Study*, Harvard Green Campus Initiative, Cambridge, MA, available online at http://green.harvard.edu/sites/green.harvard.edu/files/migrated_story_files//BlackstoneCaseStudy.pdf (accessed April 2015)

Heatherwick Studio, *UK Pavilion: Shanghai Expo 2010*, available online at www.heatherwick.com/uk-pavilion/ (accessed December 2013)

Heatherwick, T. (2013), *Making*, paperback edition, Thames & Hudson, London

Hollister, N., Klerks, K. and Wood, A. (2011), *Tall buildings in numbers*, CTUB Journal, 3, pp. 54–55

Hopping, J. A. (2006), *Development of Rapidly Deployable Structures for Military Applications: A System Based Approach to Command Post Facilities* (thesis), MIT, available online at http://dspace.mit.edu/bitstream/handle/1721.1/36747/78251990.pdf?seque (accessed April 2015)

House of Commons Library (2014), *Manufacturing: Statistics and Policy*, House of Commons Library, London, 13 November, available online at www.parliament.uk/briefing-papers/sn01942.pdf (accessed April 2015)

Howard Turner, J. T. (1977), *The London Brighton and South Coast Railway: 1. Origins and Formation*, Batsford, London

Hu, M., Bergsdal, H., van der Voet, E., Huppes, G. and Müller, D. B. (2010), *Dynamics of urban and rural housing stocks in China*, Building Research & Information, 38(3), pp. 301–317

Hunter, W. (2010), *British Pavilion by Heatherwick Studio, Shanghai, China*, Architectural Review, 14 May, available online at www.architectural-review.com/british-pavilion-by-heatherwick-studio-shanghai-china/5217803.article (accessed December 2013)

Ijey, I. (2011), *Guy's Hospital Tower refurbishment: nurse, the screens*, Building.co.uk, 8 April, available online at www.building.co.uk/guys-hospital-tower-refurbishment-nurse-the-screens/5015789.article (accessed February 2015)

Institution of Civil Engineers [ICE] (2008), *Demolition Protocol 2008*, ICE, London, available online at www.ice.org.uk/Information-resources/Document-Library/Demolition-Protocol-2008 (accessed December 2014)

International Aluminium Institute (2007), *Life Cycle Assessment of Aluminium: Inventory Data for the Primary Aluminium Industry*, London

International Aluminium Institute (2013), *2010 Global Life Cycle Inventory Data for the Primary Aluminium Industry*, London, available online at www.world-aluminium.org/media/filer_public/2013/10/17/2010_life_cycle_inventory_report.pdf (accessed February 2015)

International Aluminium Institute (2014), *Environmental Metrics Report v1.1: Year 2010 Data*, London, available online at www.world-aluminium.org/media/filer_public/2015/04/16/environmental_metrics_report_v11_14th_apr.pdf (accessed April 2015)

International Aluminium Institute (2014), *Global Aluminium Mass Flow*, London, available online at www.world-aluminium.org/media/filer_public/2014/06/19/global_aluminium_mass_flow.xlsx (accessed March 2015)

International Aluminium Institute (2014), *Regional Mass Flow Model for Japan*, London, available online at www.world-aluminium.org/publications/ (accessed April 2015)

International Aluminium Institute (2014), *Regional Mass Flow Model for Latin/South America*, London, available online at www.world-aluminium.org/publications/ (accessed April 2015)

International Aluminium Institute (2014), *Regional Mass Flow Model for the Middle East*, London, available online at www.world-aluminium.org/publications/ (accessed April 2015)

International Aluminium Institute (2014), *Regional Mass Flow Model for North America*, London, available online at www.world-aluminium.org/publications/ (accessed April 2015)

International Aluminium Institute (2014), *Regional Mass Flow Model for Other Asia*, London, available online at www.world-aluminium.org/publications/ (accessed April 2015)

International Council of Shopping Centers, *Global Shopping Center Directory*, available online at www.icsc.org/directories/global-shopping-center-directory (accessed March 2015)

International Organization for Standardization (2006), *ISO 14040:2006 Environmental Management: Life Cycle Assessment – Principles and Framework*, second edition, ISO, Geneva

Jordana, S. (2010), *UK Pavilion for Shanghai World Expo 2010 / Heatherwick Studio*, *ArchDaily*, 3 May, available online at www.archdaily.com/?p=58591 (accessed January 2014)

Kara, H. (2010), *Structural engineering: AKT's role in Heatherwick Studio's Shanghai Expo pavilion*, Architects' Journal, 8 July, available online at http://m.architectsjournal.co.uk/8602807.article (accessed February 2015)

KieranTimberlake (2011), *Cellophane House™*, KieranTimberlake, Philadelphia, PA

Klein, R. (2012), *Le pavillon du centenaire de l'aluminium, un patrimoine en pièces*, in Graf, F. and Delemontey, Y. (eds), *Architecture industrialisée et préfabriquée: connaissance et sauvegarde*, École polytechnique fédérale de Lausanne, Presses polytechniques et universitaires romandes, Lausanne, pp. 132–140

Kronenburg, R. (2012), *Live Architecture: Venues, Stages and Arenas for Popular Music*, Routledge, London

Lippke, B., Wilson, J., Perez-Garcia, J., Bowyer, J. and Meil, J. (2004), *Life-Cycle Environmental Performance of Renewable Building Materials*, Forest Products Journal, 54(6), pp. 8–19, available online at www.corrim.org/pubs/articles/2004/fpj_sept2004.pdf (accessed February 2015)

Liu, L., Aye, L., Lu, Z. and Zhang, P. (2006), *Analysis of the overall energy intensity of alumina refinery process using unit process energy intensity and product ratio method*, Energy, 31(8–9), pp. 1167–1176

Magee, L., Scerri, A., James, P., Thom, J. A., Padgham, L., Hickmott, S., Deng, H. and F. Cahill (2013), *Reframing social sustainability reporting: towards an engaged approach*, Environment Development Sustainability, 15(1), pp. 225–243

Marriott, J., Matthews, H. S. and Hendrickson, C. T. (2010), *Impact of power generation mix on life cycle assessment and carbon footprint greenhouse gas results,* Journal of Industrial Ecology, 14(6), pp. 919–928

Menzies, G. F., Turan, S. and Banfill, P. F. G. (2007), *Life-cycle assessments and embodied energy: a review*, Construction Materials, 160(CM4), pp. 135–143

Mills, M. (1999), *Greenwich Marsh: The 300 Years Before the Dome*, M. Wright, London

Morgan, C. and Stevenson, F. (2005), *Design and Detailing for Deconstruction*, SEDA Design Guides for Scotland, Issue 1, Glasgow, available online at www.seda.uk.net/assets/files/guides/dfd.pdf (accessed November 2014)

Murphy, D. (ed.) (1997), *The Work of Charles and Ray Eames: A Legacy of Invention*, Abrams, New York

Nacheman, R. J. (2006), *The Empire State Building: façade evaluation and repair of an engineering landmark*, Structure Magazine, 42, pp. 39–43, available online at www.structuremag.org/wp-content/uploads/2014/09/Empire-State-Building1.pdf (accessed February 2015)

National Gas Museum, *Gas Industry Timeline*, available online at http://nationalgasmuseum.org.uk/gas-industry-chronology/ (accessed January 2015)

National Museum Wales (2007), *From Blitz to prefab: how the Second World War altered housing in Wales*, 26 April, available online at www.museumwales.ac.uk/en/rhagor/article/blitz_prefab/ (accessed February 2015)

Orange County Government (2002), *The Regulated Recyclable Material Ordinance*, Orange County Government, Hillsborough, NC, available online at www.co.orange.nc.us/recycling/documents/ordinance_doc.htm (accessed April 2015)

Organisation for Economic Co-operation and Development (2004), *OECD/IEA Joint Workshop on Sustainable Buildings: Towards Sustainable Use of Building Stock*, Paris, available online at www.oecd.org/governance/regional-policy/35896769.pdf (accessed January 2014)

Organisation for Economic Co-operation and Development, *List of OECD Member countries: Ratification of the Convention on the OECD*, available online at www.oecd.org/about/membersandpartners/list-oecd-member-countries.htm (accessed February 2015)

Otis, P. (2014), *Recycling is the primary energy efficiency technology for aluminum and steel manufacturing*, US Energy Information Administration, available online at www.eia.gov/todayinenergy/detail.cfm?id=16211# tabs_SpotPriceSlider-2 (accessed April 2015)

Patterson, M., Martinez, A., Vaglio, J. and Noble, D. (2012), *New skins for skyscrapers: anticipating façade retrofit*, in Wood, A., Johnson, T. and Li, Q. (eds), *Asia Ascending: Age of the Sustainable Skyscraper City*, CTBUH, Chicago, IL, pp. 209–215

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

Pike Research (2012), *Global Building Stock Database*, available online at www.navigantresearch.com/newsroom/worldwide-commercial-and-residential-building-stock-will-grow-to-182-5-billion-square-meters-by-2021 (accessed April 2015)

Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, *World Population Prospects*, available online at www.un.org/en/development/desa/population/ (accessed June 2015)

Preservation Green Lab for the National Trust for Historic Preservation (2011), *The Greenest Building: Quantifying the Value of Building Reuse*, Washington, DC, available online at www.preservationnation.org/information-center/sustainable-communities/green-lab/lca/The_Greenest_Building_lowres.pdf (accessed February 2015)

Rechtin, M. (2013), *Average age of U.S. car, light truck on road hits record 11.4 years, Polk says*, Automotive News, 6 August, available online at www.autonews.com/article/20130806/RETAIL/130809922/#axzz2qHCK0Lhe (accessed December 2013)

Recycle Now, *Cans*, available online at www.recyclenow.com/facts-figures/how-it-recycled/cans (accessed March 2014)

Rice, P. (1994), *An Engineer Imagines*, Artemis, London

Rogers Stirk Harbour + Partners LLP, *Millennium Experience*, available online at www.rsh-p.com/work/all_projects/millennium_experience (accessed January 2015)

Simonen, K. (2014), *Life Cycle Assessment*, Routledge, London

Stacey, M. (2001), *Component Design*, Architectural Press, Oxford

Stacey, M. (2008), *Introduction: aluminium, architecture and sustainability*, in Ratcliffe, J. (ed.), *Aluminium & Sustainability: A 'Cradle to Cradle' Approach*, Council for Aluminium in Building, Stonehouse, 7, available online at www.c-a-b.org.uk/wp-content/uploads/080707_sustainability_s-locked-version-Justin.Ratcliffe-v1.pdf (accessed February 2015)

Stacey, M. (2008), *That just about wraps it up for the Cellophane House*, Building Design, 31 October, available online at www.bdonline.co.uk/that-just-about-wraps-it-up-for-the-cellophane-house/3126260.article (accessed December 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. (2010), *The Future Builds on Aluminium: Architecture Case Studies,* in Katgerman, L. and Soetens, F. (eds), *New Frontiers in Light Metals: Proceedings of the 11th International Aluminium Conference*, IOS Press, Amsterdam, pp. 223–230

Stacey, M. (2011), *Concrete: a studio design guide*, RIBA Publishing, London

Stacey, M. (2012), *Digital Craft in the Making of Architecture*, in Sheil, B. (ed.), *Manufacturing the Bespoke: Making and Prototyping Architecture*, Wiley, Chichester, pp. 58–77

Stacey, M. (2013), *Prototyping Architecture*, Riverside Architectural Press, Cambridge, ON

Stacey, M. (ed.) (2013), *Prototyping Architecture: The Conference Papers*, second edition, Riverside Architectural Press, Cambridge, ON

Stacey, M. (ed.) (2014), *Aluminium and Durability: Towards Sustainable Cities*, Cwningen Press, Llundain

Sulzer, P. (2004), *Jean Prouvé: Œuvre complete/Complete Works, Volume 3: 1944–1954*, Birkhäuser, Basel

Swiss Centre for Life Cycle Inventories (2010), *Ecoinvent Database v2.2*, SCLCI, Switzerland, available online at www.ecoinvent.org/database/ecoinvent-version-2/ (accessed April 2015)

Tabor, J. (1996), *Otto Wagner: Die Österreichische Postsparkasse*, Falter Verlag, Vienna

Thormark, C. (2002), *A low energy building in a life cycle: its embodied energy, energy need for operation and recycling potential*, Building and Environment, 37(4), pp. 429–435

Trenton, E. (2012), *The Application of Two Models of Life Cycle Assessment (LCA) for Transition to the Low-Carbon Economy: A Case Study in the Aluminum Industry* (thesis), *Theses and Dissertations*, Paper 791, Ryerson University

Trusty, W. B. (2004), *Renovating vs. building new: the environmental merits*, in Organisation for Economic Co-operation and Development (ed.), *OECD/IEA Joint Workshop on Sustainable Buildings: Towards Sustainable Use of Building Stock*, Paris, pp. 202–211, available online at www.oecd.org/governance/regional-policy/35896769.pdf (accessed January 2014)

United Nations (2013), *World population projected to reach 9.6 billion by 2050 – UN report*, UN News, 13 June, available online at www.un.org/apps/news/story.asp?NewsID=45165#.VO5m3Cw4jYh (accessed February 2015)

United Nations Educational, Scientific and Cultural Organization (1972), *Convention Concerning the Protection of the World Cultural and Natural Heritage*, Paris, available online at http://whc.unesco.org/en/conventiontext/ (accessed February 2015)

United Nations Educational, Scientific and Cultural Organization, *Global Strategy*, available online at http://whc.unesco.org/en/globalstrategy/ (accessed January 2014)

United Nations Population Fund, *Urbanization*, available online at www.unfpa.org/pds/urbanization.htm (accessed June 2012)

University of Florida Powell Center for Construction & Environment, *Deconstruction*, available online at www.cce.ufl.edu/projects/deconstruction/ (accessed January 2014)

US Department of Energy, *2010 Building Energy Data Book*, Washington, DC, 2010, available online at http://buildingsdatabook.eren.doe.gov/ (accessed February 2015)

US Environmental Protection Agency Office of Solid Waste (1998), *Characterization of Building-Related Construction and Demolition Debris in the United States* (EPA530-R-98-010), Washington, DC, available online at www.epa.gov/epawaste/hazard/generation/sqg/cd-rpt.pdf (accessed April 2015)

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

van Houwelingen, J. A., Boin, U. M. J. and Reuter, M. A. (2004), *Aluminium in buildings: inventory and collection during demolition*, in Vázquez, E., Hendriks, C. F. and Janssen, G. M. T. (eds), *PRO 40: International RILEM Conference on the Use of Recycled Materials in Buildings and Structures, 8–11 November 2004, Barcelona, Spain*, RILEM/SAPL, Bagneux, pp. 193–200

Vénacque, A. (2001), *Jean Prouvé: Le pavillon du Centenaire de l'aluminium*, Editions Jean-Michel Place, Paris

Vitra (2012), *Sustainability Report 2012*, Vitra, Birsfelden, available online at www.vitra.com/en-gb/corporation/sustainability (accessed December 2013)

Waite, R. (2010), *Shanghai 2010: 'Seed Cathedral' will not be sold says FCO*, Architects' Journal, 2 September, available online at www.architectsjournal.co.uk/news/daily-news/shanghai-2010-seed-cathedral-will-not-be-sold-says-fco/8605455.article (accessed February 2015)

White, M. (2013), Keynote: *Third Generation Light Weight Vehicle Architecture*, in Stacey, M. (ed.), *Prototyping Architecture: The Conference Papers*, second edition, Riverside Architectural Press, Cambridge, ON, pp. 390–407

World Aluminium, *Statistics*, available online at www.world-aluminium.org/statistics/ (accessed January 2014)

World Green Building Council (2009), *Six Continents, One Mission: How Green Building is Shaping the Global Shift to a Low Carbon Economy*, Toronto, CA, p. 12 and p. 17, available online at www.www.gbcsa.org.za/wp-content/uploads/2013/06/WGBC-Report-2009-Six-Continents-One-Mission.pdf (accessed April 2015)

Websites

Aluminium for Future Generations, http://recycling.world-aluminium.org/home (accessed January 2014)

Campagnolo, www.campagnolo.com/jsp/en/index/index.jsp (accessed February 2015)

Department of Transport, www.standardsforhighways.co.uk/mchw/vol1 (accessed April 2015)

The Future Builds with Aluminium, http://greenbuilding.world-aluminium.org/home.html (accessed March 2014)

IKEA Foundation, www.ikeafoundation.org (accessed January 2014)

Sistema IBGE de Recuperação Automática, www.sidra.ibge.gov.br/ (accessed March 2015)

The Skyscraper Center: The Global Tall Building Database of the Council on Tall Buildings and Urban Habitat, www.skyscrapercenter.com/ (accessed January 2015)

United Arab Emirates National Bureau of Statistics, www.uaestatistics.gov.ae/ (accessed April 2015)

United Nations Refugee Agency, www.unhcr.org/ (accessed January 2014)

United Nations Statistics Division, http://unstats.un.org/unsd/default.htm (accessed March 2015)

image credits

Image Credits

The author and publisher have made every effort to contact copyright holders and will be happy to correct, in subsequent editions, any errors or omissions that are brought to their attention.

Adams Kara Taylor, 4.85

AHMM, 2.80–2.86

Albert Vecerka/Esto (KieranTimberlake), 2.42, 4.67

Aluminium Français, 4.46

Aluminium Français (Jean Prouvé), 4.53, 4.54

Aluminium Français (Lucien Alff), 4.27, 4.28, 4.30–4.32

Aluminum Group, 6.5

Architects' Journal, 4.10

Architectural Review, 4.90

Archive Maps, 3.2

Artcurial, 4.45

Athena Institute, 2.15

Axel Vénacque, 4.29, 4.36–4.39, 4.41, 4.42

Bennetts Associates, 5.5

Bodleian Libraries, University of Oxford, 2.14

Brookes Stacey Randall Fursdon, 2.23, 2.51, 2.77–2.79, 2.92

Brookes Stacey Randall, 3.22

Bruner/Cott (Rick Mandelkorn), 2.25

Building Design, 2.13

Chantelle Niblock, 2.55, 2.56, 2.58, 2.63, 2.65, 5.25, 5.26

Chetwoods Architects, 3.29, 3.30, 3.46, 3.47

Chris Grech, 2.40

Colin Streater, Building.co.uk, 2.50

Curve Workgroup, 6.6

Daniele Mattioli, 4.84

David Rumsey, Google Maps, 3.4

Delta Metal Plc, 3.12

EDINA Ordnance Survey Service, 3.3, 3.11, 3.14, 3.15, 3.17, 3.21, 3.24, 3.25, 3.27, 3.35, 3.40, 3.45

Environment Agency Abu Dhabi, 5.23, 5.24

European Aluminium Association, 2.33, 2.34, 2.36, 2.38

Fluid Structures, 6.27–6.38

Foreign Office Architects, 3.37

Foster Associates, 6.14–6.16

Foster + Partners, 3.28, 3.33

FPE Architects, 2.66–2.68

Freeserve.co.uk, 4.23

Friedbert Vogelgsang, 4.55

George Washington Danforth, 3.5

Greenwich Peninsula Regeneration Ltd, 3.31

Harry Seidler & Associates (John Gollings), 5.28

Heatherwick Studio, 4.81–4.83, 4.86–4.89

Heathrow Photo Library, 2.9

Humweb.ucsc.edu, 4.13, 4.14

Ian Lambot, 5.17, 5.18

Ideal-homes.org.uk, 3.10, 3.13, 3.16

Inhabitat.com, 4.15

Jean Prouvé Archive, 6.3

KieranTimberlake, 2.48, 4.68–4.71, 4.73, 4.74

Lawandborder.com, 4.12

London Transport, 3.20

Luke Hayes, 4.78, 4.79

Martine Hamilton Knight, 5.8

Marshall Gerometta, 2.17

Michael Ramwell, 3.26, 3.44, 3.53

Michael Stacey, 2.2, 2.8, 2.10, 2.22, 2.43–2.47, 2.69, 3.1, 3.6, 3.36, 3.38, 3.39, 3.41, 3.43, 3.49–3.52, 3.54–3.58, 4.5, 4.9, 4.11, 4.75, 4.76, 4.80, 5.2, 6.21–6.26

Michael Stacey Architects, 2.3, 2.5–2.7, Table 2.2, 2.19, 2.20, Table 2.3, 2.24, Table 2.4, 2.30–2.32, Table 2.5, Table 2.6, 2.51–2.53, 2.62, 3.23, 5.6, 5.9, 5.11, 5.12, 6.1

Mingming Hu et al., 5.15, 5.16

Ministry of Health/Ministry of Works, 4.2, 4.4

National Library of Scotland, 3.9, 3.19

Nic Lehoux, 5.4, 5.7

Nicola Saijeh, 5.22

Old-maps.co.uk, 3.7, 3.8

Pablo Casals, 5.21

Penoyre & Prasad Architects, 2.75, 2.76

Peter Aaron/Esto (KieranTimberlake), 2.41, 4.64, 4.65

Peter Aaron/OTTO (KieranTimberlake), 4.62, 4.63, 4.66, 4.72

Peter Bell & Partners, 2.70, 2.71

Peter Cook, 5.3

Peter Durant, 2.49

Peter Sulzer, 4.56–4.58, 6.4

Pike Research, 2.1

Public Domain, 2.18

Quintain Plc., 3.42

Renzo Piano Building Workshop, 4.59–4.61, 6.10–6.13, 6.17–6.20

John Maltby/RIBA Library Photographs Collection, 4.26

Richard Rogers Partnership, 3.32, 3.34

Richard Klein, 4.40–4.44

Riken Yamamoto & Fieldshop, 5.19, 5.20

Ron Fitch, 6.8, 6.9

SANAA and Arup, 4.77

Saucier + Perrotte, 4.21

Sébastien Frémont, 4.47–4.52

Spiegel.de, 4.16

Sprung.com, 4.17–4.20

Staab Architekten, 2.72–2.74

Stanleyhistoryonline.com, 4.6–4.8

Stewart Brand, 5.1

Stone Foundries of Greenwich, 3.48

Structure Magazine, 2.54, 2.64

Studio Egret West, 2.87–2.91

Skidmore, Owings & Merrill, 2.21, 2.57, 2.59–2.62, 6.2

Suffolk County Council, 2.11, 2.12

Telegraph.co.uk, 4.1, 4.22, 4.24, 4.25

Vintage.es, 3.18

Vitra, 6.7

Vitralu (André Lannoy Sr, André Lannoy Jr), 4.33–4.35

Wilkinson Eyre Architects (Craig Sheppard), 5.27

West Dunbarton, 4.3

World Aluminium, 2.4, 2.16, 2.26–2.29, 2.35, 2.37, 2.39, 5.10

World Aluminium (Marlen Bertram), 5.29–5.32

Zaha Hadid Architects, 5.13, 5.14

acknowledgements

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

KieranTimberlake

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.

www.kierantimberlake.com

Architecture and Tectonics Group at The University of Nottingham

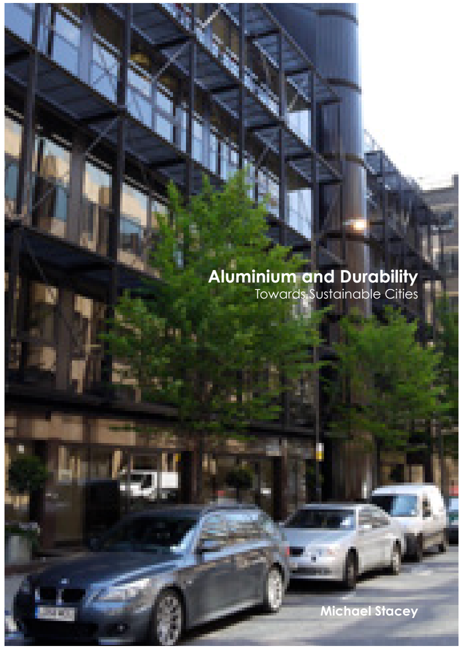
The Architecture and Tectonics Research Group [ATRG] addresses the core of architecture including design as research and research that supports and stimulates the design of high-quality contemporary architecture and infrastructure. Themes within this research group include: architecture as a discipline, 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

Acknowledgements

The Towards Sustainable Cities Research Team would like to acknowledge the input into this research of:

- Chris Bayliss (Deputy Secretary General) and Marlen Bertram (Director – Product Stewardship) of the International Aluminium Institute [IAI];
- Stephanie Carlisle, Efrie Friedlander and Billie Faircloth of KieranTimberlake;
- Bernard Gilmont, Director of Building &Transport Groups, European Aluminium [EAA];
- Christian Leroy, Founder and Director of Metals Sustainability Consulting;
- Tom Siddle, Technical Manager of the Aluminium Federation [ALFED];



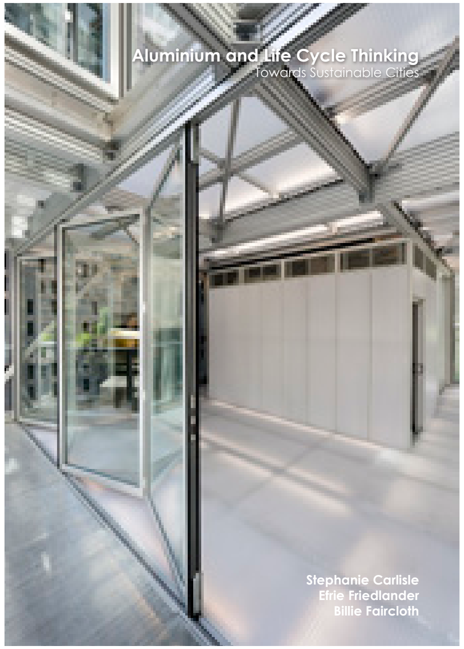
Aluminium and Durability

The durability of aluminium is probably one of the most important qualities of this metal when used to form architecture and infrastructure.

This book charts over 100 years of the use of aluminium in architecture and the built environment using 50 built works from 1895 to 1986, with four historic exemplars being inspected and presented in depth.

Twelve twentieth-century award-winning and historically significant aluminium-based buildings were inspected, leading to the successful non-destructive testing of aluminium finishes on three of these projects.

Written and edited by Michael Stacey.



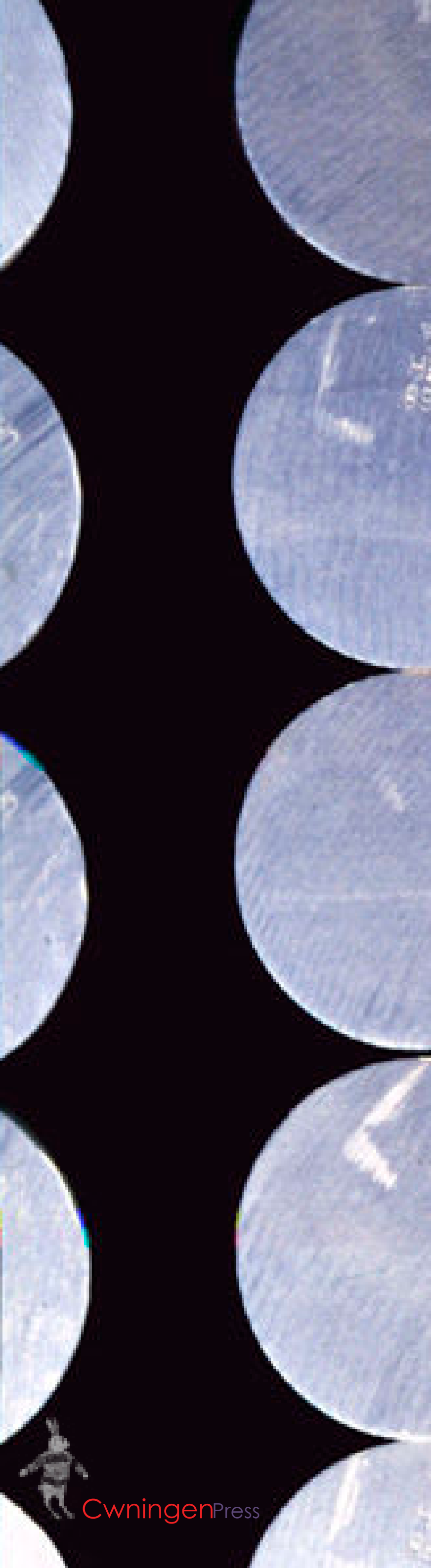
Aluminium and Life Cycle Thinking

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.

The **Towards Sustainable Cities Research Programme** is funded by the International Aluminium Institute [IAI] and undertaken by Michael Stacey Architects with KieranTimberlake and the Architecture and Tectonics Research Group [ATRG] of The University of Nottingham. The research is structured around the primary benefits of aluminium, as articulated by 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.

Demolition of Heathrow Terminal 2,
September 2010



Aluminium Recyclability and Recycling

Towards Sustainable Cities

Aluminium Recyclability and Recycling, written by Michael Stacey with researchers Laura Gaskell, Jenny Grewcock, Michael Ramwell and Benjamin Stanforth, and with further input from Stephanie Carlisle, Efrie Friedlander 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.

Aluminium is almost infinitely recyclable and this is well understood. This research identifies that aluminium-based projects dating back to 1950 (the first year of entries in the IAI's global mass flow model) that have been disassembled have all been recycled. 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.

CwningenPress