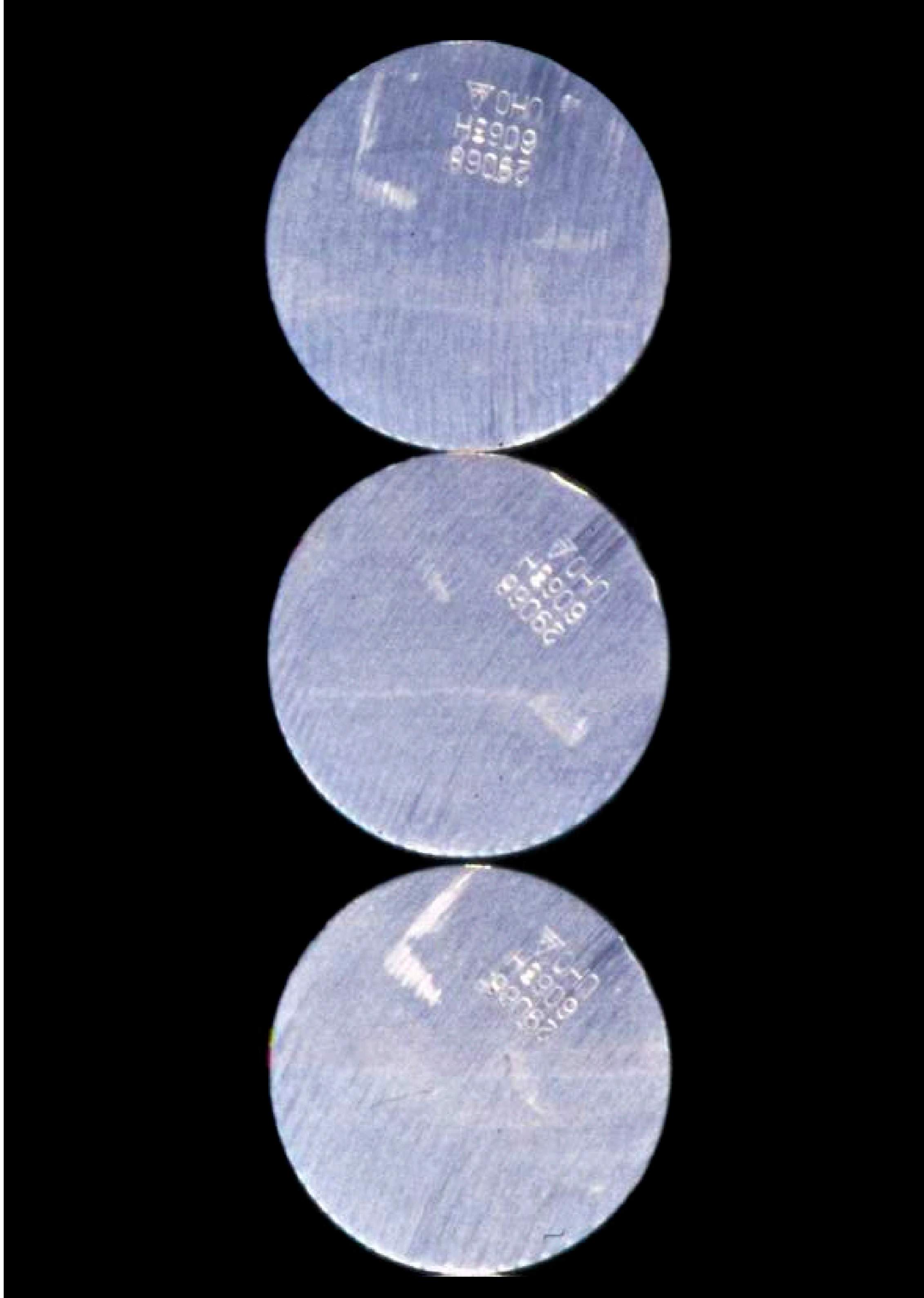
Aluminium: Sympathetic and Powerful

Towards Sustainable Cities

Michael Stacey



International Aluminium Institute

Nottingham + Llundain

Front cover image The Hive, Wolfgang Buttress, Milan Expo 2015

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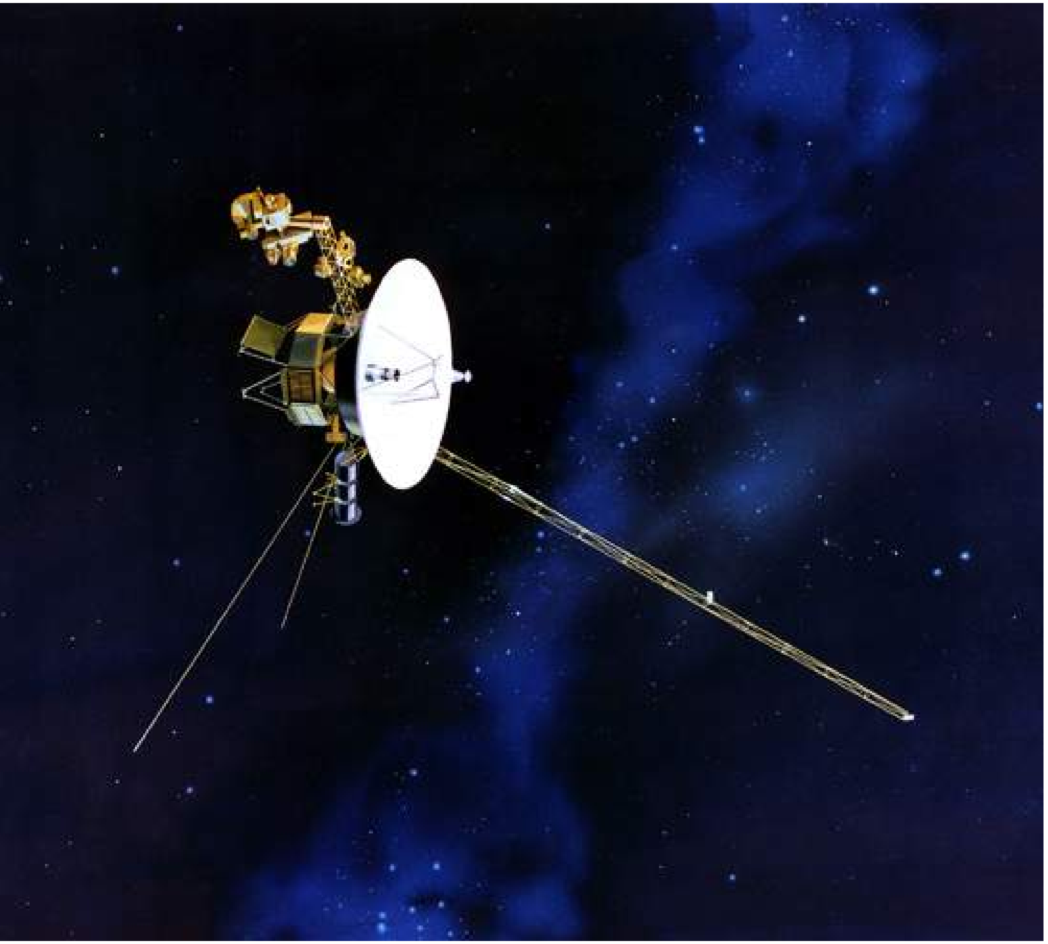
Aluminium: Sympathetic and Powerful

Towards Sustainable Cities

Michael Stacey Architects

KIERANTIMBERLAKE

The Voyagers were ready to be sent on their way
And the golden record mounted, with a needle to make it play
They launched them in September [1977] from Cape Canaveral
The furthest man made objects
They are out there moving still
Beyond our solar system
There is a golden calling card
.....
Sounds of Earth
Jim Moray (2017)[1]



1 J. Moray, (2017), *Sounds of Earth*, BBC Folk Awards 2017, CD, transcribed by the author. Voyager Two launched from Cape Canaveral, Florida, USA on 20 August 1977, aboard a Titan-Centaur rocket. Followed by Voyager One on 5 September 1977, also aboard a Titan-Centaur rocket, launched from Cape Canaveral.

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introduction

Introduction

Aluminium Sympathetic and Powerful is the fifth report, or book, of the Towards Sustainable Cities (TSC) research programme, following on from *Aluminium and Durability, Aluminium Recyclability and Recycling, and Aluminium Life Cycle Thinking, and Aluminium: Flexible and Light*. The objective of the Towards Sustainable Cities (TSC) research, 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, B-Made at the Bartlett, University College London and KieranTimberlake of Philadelphia, Pennsylvania, USA. Michael Stacey is the director of this research programme.

Fig 1.1 Students of studioMARS, from The University of Nottingham, School of Architecture experiencing the Peace Bridge (2011) in Derry/London Derry, Northern Ireland, designed by architect WilkinsonEyre, on a wet and stormy night, November 2014.

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 Towards Sustainable Cities (TSC) research programme is structured around the primary benefits of aluminium as articulated by *The Future Builds with Aluminium* website, *http://greenbuilding.world-aluminium.org* and *The Aluminium Story website*, *http://thealuminiumstory.com*. The first four books: *Aluminium and Durability, Aluminium Recyclability and Recycling, Aluminium and Life Cycle Thinking*, and *Aluminium Flexible and Light,* can be downloaded as PDFs via www.world-aluminium.org/publications.

A primary aim of this research programme 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. [1]

Lord Norman Foster has suggested that the city is the greatest invention of humankind, 'the future of society is cities, but what makes a city work? The city is about values, about aspirations, they are enlightening as well as offering prosperity.' [2]

Fig 1.2 Dr James Fox in central Tokyo, courtesy of BBC 4

Fig 1.3 The Thames River, central London – aluminium has become the background material of our contemporary cities. Image courtesy of British Land, Oxford Properties and RSHP

Dr James Fox discussing cities and in particular cities in Japan considers that:

> 'Over the centuries cities have inspired some of Japan's greatest art. But they are themselves creations, dynamic complex and often beautiful. This is a story of Japan's urban imagination and three great cities built its art and culture.
>
> In Kyoto the Japanese mastered beauty and elegance. In Edo they found their often-mischievous voice and in Tokyo they turned destruction onto creation. And in the process they helped define a country as it relentlessly searched for itself.
>
> Cities are engines of cultural change, because they throw people together to compete and collaborate and innovate. It the case around the world, but I can't think of many countries more defined by their cities than Japan.'[3]

Cities are now the home for over half of humanity, however this should not be a concern. It should mean that humankind hones its skills in designing and developing cities within climate change targets of carbon usage, whilst protecting the overall biodiversity of planet Earth.

This fifth book focuses on the role of aluminium in the built environment and how as a material, which offers durability yet can be almost infinitely recycled, it can be considered as being sympathetic to human ecology and powerful in its many applications. Chapter Six reviews examples of maximising the potential of aluminium, rather than the wholesale replacement of other materials in construction. Thus, highlighting the benefits of aluminium when combined with other materials, and with thoughtful design and careful detailing - from the ability of an aluminium curtain wall extrusion to integrate silicone gaskets and gently retain a triple glazing unit, to the efficiency of an aluminium road bridge deck with just a thin epoxy wearing or road surface.

The introduction to *Aluminium: Flexible and Light* explored whether the present time period should, in geological terms, be defined as the **Anthropocene**? Describing an epoch where humankind has altered the environment and ecology of Earth to the extent that it is being recorded in the Earth's crust, in the very rocks of planet Earth.[4] Writing in The Anthropocene Review (March 2014) Jan Zalasiewicz, Mark Williams and Colin Waters of the University of Leicester with Anthony D. Barnosky and Peter Haff, suggest the weight of the planet Earth's **technosphere** has reached 30 trillion tonnes.[5] Jan Zalasiewicz and colleagues note: 'The technosphere comprises the interconnecting technological systems that underpin modern civilization', citing Haff (2012).[6] They continue, it 'is a phenomenon that has now reached a scale sufficient to perturb the natural physical chemical and biological cycles of the Earth' citing Rockstron et al., (2009). 'This provokes 'the suggestion of an Anthropocene Epoch', citing Crutzon (2002).[7]

Fig 1.4 Extruded tubular sections, before straightening at Sapa, Tibshelf Plant, Derbyshire, England, architect, Foster Associates, 1973

In a paper entitled Changes,[8] inspired by David Bowie's song, released on 7 January 1972, *'Time may change me, but I can't trace time,*[9] Chris Bayliss' observations include:

> In 1972, global primary aluminium production was 12 million tonnes (Mt), and recycled production was around 2.5 Mt, of which only 0.5 Mt was from post-consumer scrap – predominantly automotive castings. **Semis** shipments totalled around 14 Mt.[10] [Noting that semis is an industry shorthand for semi-fabricated or semi-finished products and is defined in the Glossary].
>
> At a similar time, the seeds of European, North American and Japanese de-industrialisation were being sown[11], as costs of energy and labour rose and early twentieth century production capacity came to the end of its natural life. Similarly, new centres of production were being born in the Middle East (Alba 1971; Dubal 1979), South America (Alcominas 1965; Aluar 1974), Australia & New Zealand (Kurri Kurri 1969; Tiwai Point 1971; Boyne Island 1979) and

South Africa (Bayside 1971), close to sources of long term, competitively priced energy and/or raw materials. In summary, 2017 has seen primary production shifting from many of these "new" areas, as competition has increased for limited energy resources (e.g. Brazil, South Africa) and as resource-rich areas focus on upstream parts of the value chain (e.g. Australia, Brazil).[12]

In 1972:

- 3.7 billion global population
- 60 per cent of the world's population lived in extreme poverty (living with less than US$1.90 per day);
  - down from 86 per cent in 1888, the year that Julia Brainers Hall, Charles Martin Hall and Paul Héroult invented the **Hall- Héroult process** (pop. 1.6 billion), down from 95 per cent in 1825, the year that Hans Christian Ørsted first produced aluminium (pop. 1.1 billion);
- Global child mortality (survival to 5 years old) was 14 per cent;
  - down from 38 per cent in 1880;
- Global average life expectancy at birth: 60 years (from 30 in 1888);
- 56% literacy rate;
- Population growth rate had just peaked at 2.2 per cent in 1962/63;
- 37 per cent of the world's population lived in cities.*

In 2015:

- 7.4 billion population;
- 10 per cent living in extreme poverty;
- Child mortality at 4 per cent;
- Global average life expectancy at birth: 71.4 years;
- 85% literacy rate;
- Global population growth rate is 1.1 per cent;
- 54% of people live in cities. *

All data except * from the excellent Max Roser (2016) – 'A history of global living conditions in five charts', * from The World Bank.[13]

Ten years ago it took on average 14.3 kWh of power (DC) to produce one kilogram of aluminium from alumina, today it takes 13.4 kWh. [14]

In the second decade of the twentieth century, we are in the midst of an even more spectacular shift, a generational change in centres of production and consumption, both in terms of location and sheer volume.[15]

One and a quarter billion tonnes of primary aluminium has been produced since 1900; over one billion of that (almost 90 per cent) has been produced since 1972. Around 75 per cent of that volume is still in use… in lightweight cars, in tough Apple MacBooks and protective drinks cans, in durable window frames and photovoltaic panels,

Fig 1.5 The Hive the United Kingdom's Paviliion at Expo 2015 in Milan, Italy, designed by Wolfgang Buttress

in art and machinery. And while in 1972 it was to the traditional markets of Europe, Japan and North America that aluminium flowed. Today, as well as those regions, it services the needs and improving quality of life of the billions of people in other areas.[16]

A key question for specifiers of aluminium **alloys** in the twenty-first century is where the aluminium comes from and what is the **power mix** of that region. It is possible within a performance specification for a building to successfully request only hydroelectrically produced aluminium. Michael Stacey Architects achieved this for Bennetts Associates on the rooflights of the Sophos Operational

Fig 1.6 TThe extruded aluminium keyboard used to set out this book in inDesign

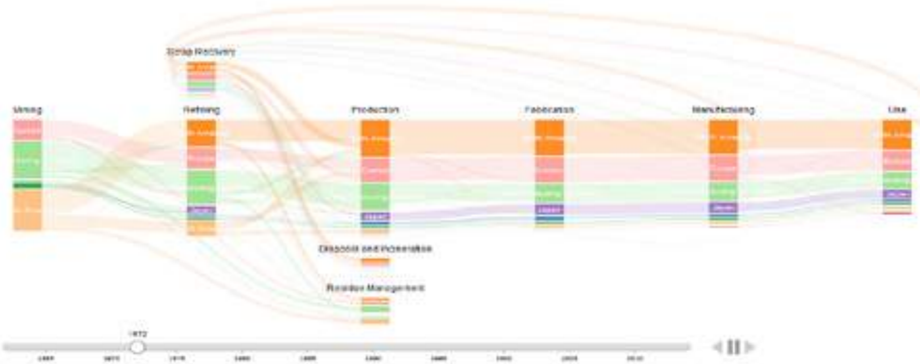

Fig 1.7 Global Aluminium Mass Flow for 1972,, courtesy of the International Aluminium Insitute (IAI)

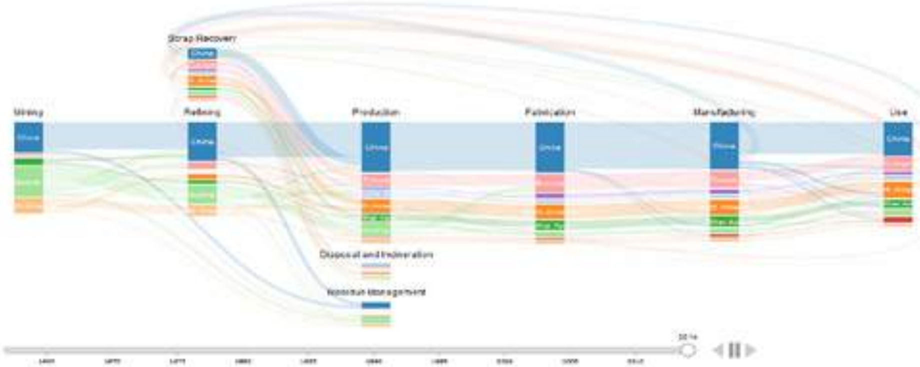

Fig 1.8 Global Aluminium Mass Flow for 2014, courtesy of the IAI

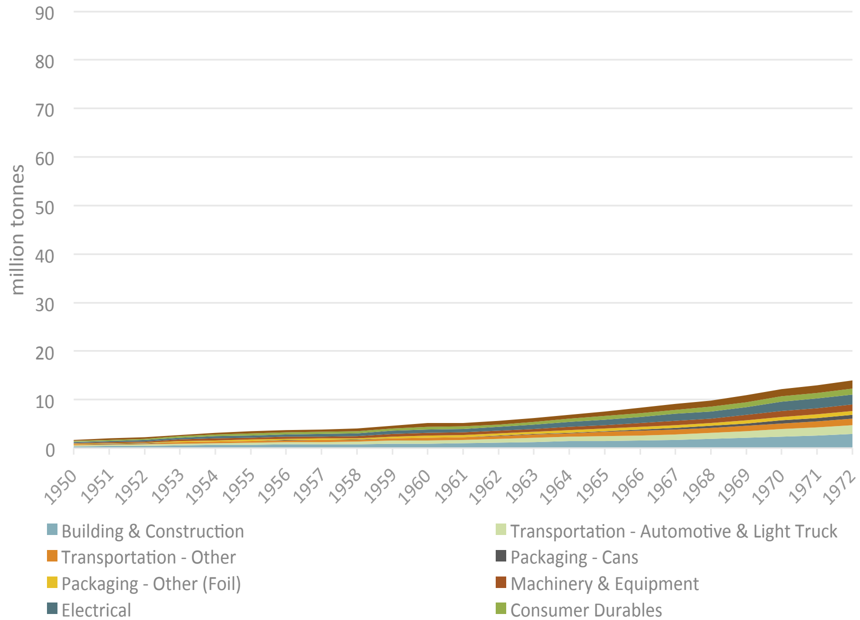

Fig 1.9 Global semi-fabricated net shipments to market segments, 1952-1972, courtesy of the IAI

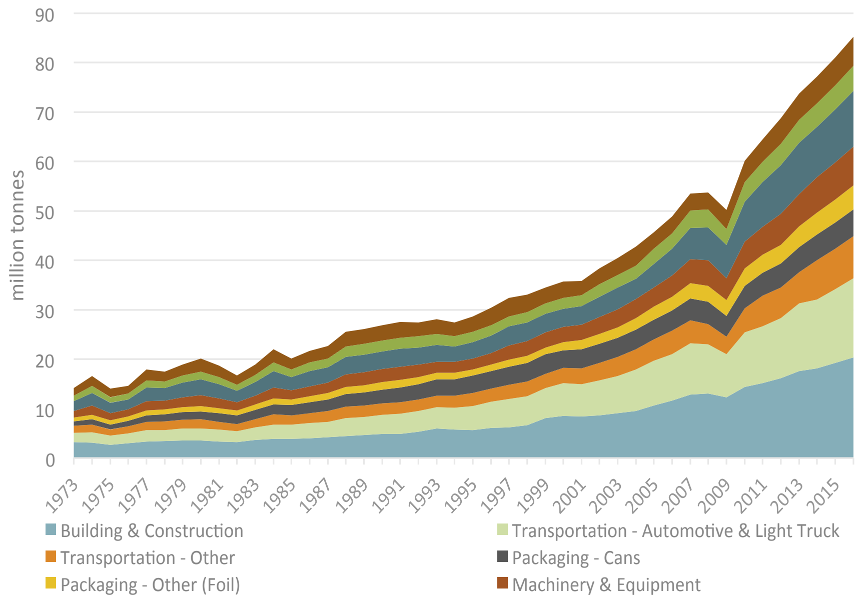

Fig 1.10 Global semi-fabricated net shipments to market segments, 1973 - 2015, courtesy of the IAI.

Fig 1,11 Niagara Falls: 96% of the energy used in Québec is from renewable sources including hydroelectricity

Headquarters in Abingdon, Oxfordshire, England. The aluminium extrusions of the rooflights were sourced, using a competitive tender process, from a region that uses a high percentage of hydroelectric power to smelt aluminium. In the case of Sophos, the aluminium extrusions were sourced from Québec, Canada, where the power mix is 96 per cent hydroelectricity. Another important decision was to source the relatively heavy and bulky sealed double glazed units, which completed the rooflight assembly, in the United Kingdom. The carbon impact of a sea container full of extrusions did not distort the overall carbon saving and embodied impacts.

It is likely that, in the near future, we will see aluminium develop as a regional material with well understood embodied impact studies, using **life cycle assessment (LCA)** techniques. Oliver Moss observed in 2015 that: 'approximately 47 per cent of the aluminium processed annually is made up of recycled material.'[17] Thus, the **recyclability** of the aluminium within a component at the end of it's useful life is much more important than its recycled content.

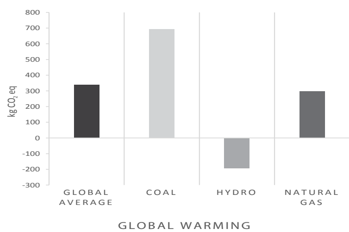

Fig 1.12 Globalwarming potential of the global average for electricty comparedwith hydroelectricty

Circular Economy

A circular economy is defined by M. Geissdoerfer, et al (2017) as a regenerative system in which resource input, waste, emissions, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, **reuse**, remanufacturing, refurbishing, and recycling.[18] The concept of a circular economy, in its contemporary form, was first proposed by two British economists David W. Pearce and R. Kerry Turner in 1989 in their book, *Economics of Natural Resources and the Environment.*[19] In the eighteenth and nineteenth century many estates in the United Kingdom were run using a sustainable circular economy, for example Llanerchaeron near Aberaeron, Wales, the estate of the Lewes family, where the house designed by architect John Nash was completed in 1795. This estate was fully self sufficient in terms of fuel, meat and vegetables; however, it was dependent on a rigid class structure, an abundance of cheap labour and the exploitation of a global Empire. This lasted for about eight generations of the Lewes family dating back to 1634, although it proved to be unsustainable in the long term. This social order was disrupted by the First World War, with a high number of casualties from the British Army, including men from all classes of the population; working, middle and upper class, a like.[20] Llanerchaeron is now owned and managed by the National Trust.

Fig 1.13 The kitchen courtyard of Llanerchaeron, Wales, architect John Nash, 1795

Sapa's collaborative Soluxio Solar Lamppost is modular, **designed for disassembly** (**DfD**), solar powered, highly integrated and intelligent. It is also an exemplar of a circular economy. This is a twenty-first century product, which utilises aluminium extrusions that are circular in form to make the lamppost structurally efficient, and thus slender, elegant and aerodynamic. The lamppost integrates solar cells in a circular glass enclosure, which is not dependent on orientation, and means that the lampposts can be placed as needed to provide street and pavement lighting. The vertical mounting of the solar cells limits the effects of snow and dirt on their performance. Anti-glare and dirt shedding coating are options offered by Solution Lighting and Sapa Pole Products. The Soluxio Solar Lamppost is a truly global product that can be extruded and fabricated on a regional basis by Sapa. It is offered in a height range of four to 14m, in two-meter increments. Clearly these solar lampposts offer higher outputs in areas of high insolation, such as the Middle East. The output of a four-meter lamppost in Dubai compared to London is over 50 per cent higher. The lampposts can take a range of lamp heads and are typically equipped with high efficiency LED luminaires. The lithium batteries are integrated into the core of the lampposts extruded mast. The batteries are sized to be enable a continuous power supply during periods of inclement weather. The batteries need to be changed every eight to ten years. Typically the lampposts are offered with highly durable silver **anodising**.

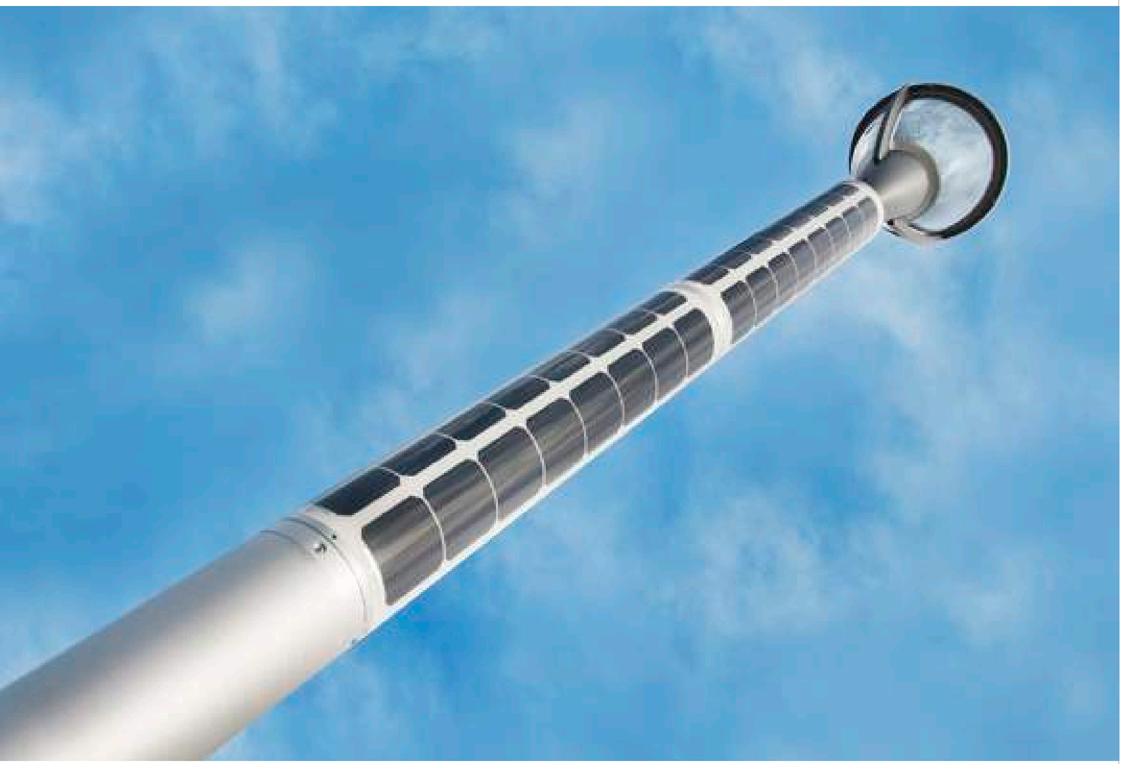

Fig 1.14 Soluix/Sapa solar powered extruded aluminium lamppost

The extrusion of the Soluxio Solar Lampposts has been designed to enable the integration of CCTV cameras, positional GPS locators, remote sensors and wireless communication. A version of the lamppost can be equipped as a mast for cellular telephone networks.

Soloxio/Sapa Lighting offer its Soluxio Solar Lampposts as part of a circular economy in regions of the world with existing street lighting provision. They work with the local government or land owner (such as a university campus) when a low carbon more energy efficient provision is desired and needed. Sapa/ Soloxio Lighting will collect and recycle the existing lampposts, before installing the new street lighting. The new Soluxio Solar Lampposts can also be relocated or recycled in the future if there are changes in the street pattern or usage, the lampposts are designed for disassembly (DfD) should they eventually become obsolete or not needed - the aluminium is almost infinitely recyclable.

Soloxio/Sapa Lighting has designed an autonomous version of its solar lamppost for regions of the world with out grid-based electricity. The Soluxio XS, is the autonomous 'little brother' which can be used off grid and for temporary installations, this product is pitched as using the same technology but at an optimised cost.

Soloxio/Sapa Lighting also offer circular aluminium solar powered NxT bollards and circular aluminium solar powered road warning lights. The Sapa/Soluxio range of solar powered lampposts and bollards are global aluminium-based products that are both sympathetic and powerful.

Fig 1.15 KfW Westerkade offices in Frankfurt, architect Sauerbruch Hutton, 2010

Microns Matter in Contemporary Architecture

The human eye is arrested by the surface of a building. In daylight the human eye can discern the texture of the building envelope, its colour, reflectance and in the case of aluminium panel whether they are perforated, even from many, many meters away.[21] Finishes on aluminium is a tale of continuous and steady improvements over the past 40 years, based on long term testing and improved processes and formulation. It is now possible to specify polyester powder coating that appears black (RAL 9005) to the human eye yet provide a reflectance of infrared light that is 25 per cent higher.[22] Infrared light is invisible to the human eye, however, it accounts for 49 per cent of solar gain on a sunny lit roof or wall. Megadur® Powder Coatings produce a Cool Coating polyester powder coating, which is Qualicoat Class 2 approved, proving an ultra durable coating that is offered with a 40-year life expectancy until the need to repaint. Noting that the polyester powder coated aluminium needs to be washed periodically, the frequency of cleaning is dependent on location.[23] Axalta produces Alestra® Cool, which is up to 20 per cent more reflective than conventional dark polyester powder coatings. When tested Alestra® Cool black Ral 9005 provides the same level of reflectance as a standard white power coating Ral 9010.[24] High reflectance power coatings reduce the surface temperature of aluminium components, including roof sheeting, cladding and curtain walling, when subject to solar radiation. This can reduce the energy required to cool a building by limiting solar gains, also reducing the thermal cycling of the aluminium component, due to thermal explanation resulting for such heat gains. The linear coefficient of thermal expansion for an aluminium alloy 6061 used in curtain walling and window section is 2.32×10^{-5} K^{-1}. Thus a 3-meter long 6061 section subject to a temperature increase of 40° C will become almost 3millimeters longer. Furthermore, insulation materials such as expanded polystyrene have a melting point of 80° C. In Northern Europe a conventional black polyester coated aluminium cladding panel on a sunny summer day easily reach a surface temperature of 90° C, which in the case of a composite panel will cause delamination. Highly reflective polyester powder coatings eliminates this risk.

Polyester powder coating manufacturers, including PPG and Akxo Nobel, offer ultra durable polyester powder coatings in a bold range of colours including metallic silvers and greys, and even a soft coral pink – similar to the colour used on the original Harrods escalator cladding, discussed in Chapter Six, see pages 150–159. The durability of aluminium is discussed in detail in TSC Book One: *Aluminium and Durability*. An architectural practice that demonstrates great skill in the use of colour in architecture, combined with a deep commitment to sustainability is Sauerbruch Hutton. The KfW Westarkade office building in Frankfurt, Germany, designed by Sauerbruch Hutton, was completed in 2010 and is an exemplar green office building. This 15storey high building for the government-owned German development bank has a primary energy consumption of only 100kWh/m^2. This is achieved using an aluminium framed double façade, with an outer single pane of clear glazing. The narrow vertical glazed panels in the faceted facades provide summer time cooling, also introduce colour. Every other pane in the clear double-glazed inter skin is an openable window. The average U-value of the glazing system is 1.1 W/m^2 K. Felix Mara, in reviewing this project suggests: 'Zoom in and you return to the beautiful world of the detail, the materials and the vivid colour – the qualities which come to mind when Matthias Sauerbruch refers to joie de vivre'.[25]

The Shard, designed by Renzo Piano and his Building Workshop (RPBW) in collaboration with Adamson Associates (Toronto, London), is also known as the London Bridge Tower. This 72storey mixed-use tall building is located at London Bridge Station on the south bank of the River Thames, in central London. This project is a response to the urban vision of the then London Mayor Ken Livingstone and to his policy of encouraging high-density development at key transport nodes in London. This sort of sustainable urban development relies on proximity to public transportation, which discourages car use and helps reduce traffic congestion in the city. At 309.7m, the Shard is the tallest building in the United Kingdom and was briefly the tallest building in Europe.

It is clad through with an all glass unitised aluminium curtain walling system, designed and installed by Permasteelesa in response to RPBW's visual and performative criteria. In total, 11,000 untised panels of double-skinned curtain walling are used for the Shard's building envelope. RPBW described the skin of the Shard as:

> The extra-white glass [low Iron glass] used on the Shard gives the tower a lightness and a sensitivity to the changing sky around it, the Shard's colour and mood are constantly changing. It required a particular technical solution to ensure the facade's performance in terms of controlling light and heat. A double-skin, naturally ventilated facade with internal blinds that respond automatically to changes in light levels was developed. The logic is very simple: external blinds are very effective in keeping solar gain out of a building, but unprotected external blinds are not appropriate for a tall building, hence the extra layer of glass facade on the outside.[26]

Fig 1.16 Guy's Hospital overcladding designed by Penoyre & Prasad and the Shard, designed by Renzo Piano Building Workshop: have equally durable but distinct finishes on their aluminium building envelopes – anodising and Class 2 polyester powder coating

The extruded aluminium sections of the curtain walling are coated in Qualicoat Class Two polyester powder coating. This ultra durable polyester powder coating comes with a 40-year guarantee, subject to period cleaning, which is undertaken by skilled abseilers. At 72storeys, delaying the requirement for repainting, whilst marinating the visual quality of the architecture, is important for the long-term stewardship of this project.

The Shard opened, with its combination of offices, restaurants and apartments, all topped by a viewing deck, in 2013. In the same year, the Shard's client, Sellar Property Group, appointed RPBW to design a slender residential tower with generous public realm amenities at street level, to complement the now occupied Shard. RPBW considered this second scheme to be 'both respectful of its historic context on St Thomas Street through the choice of facing materials, while clearly acknowledging the cluster established by The Shard. The 26storey tower, a third the height of the Shard,

Fig 1.17 A Just Eat Starship delivery robot on test in Greenwich, London, 2016

steps back in section, maintaining sight lines of The Shard in local views. At the scale of the city, the proportions of The Shard remain unchanged.'[27]

Mobility and Aluminium

Acemoglu and Restrepro in their paper *Secular Stagnation? The Effect of Aging on Economic Growth in the Age of Automation*[28]; demonstrate that an aging population does not inhibit economic growth. Suggesting that 'this counter intuitive finding might reflect the more rapid adoption of technologies in countries undergoing pronounced demographic change'[29] with an aging population. Aluminium and its alloys have a key role to play in this process, from the humble lightweight aluminium walking stick to the aluminium armature of a robot, which are extensively used in industry and are increasingly entering our homes, or at least delivering to them.

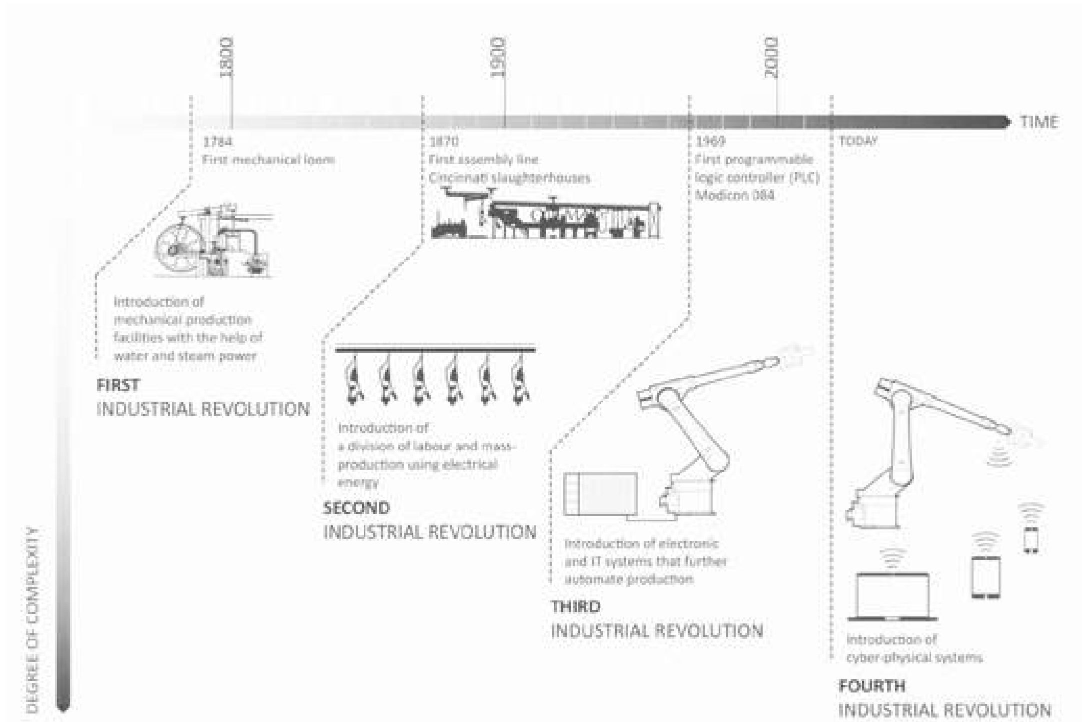

Fig 1.18 The four major steps in industrial development – from the industrial revolution of the eighteenth century to the 'fourth' industrial revolution enabled by digital technology and robotics (diagram courtesy of Achim Menges)

Running at one to one

A joint venture by Brunel University, Constellium and Jaguar Land Rover established the Advanced Light Metals Processing Research Centre on Brunel campus in Uxbridge, Middlesex, England, in 2013. This joint venture won a £4.4M (Euro 5.1M) grant from the Engineering and Physical Sciences Research Council (EPSRC) in the United Kingdom for the creation of a national facility to scale-up design and development opportunities in automotive light metals research. Brunel University supplemented this with a further grant of £2.5M (Euro 2.9M) to build a dedicated facility and provide supporting resources.[30] The Advanced Light Metals Processing Research Centre includes DC casting and an extrusion laboratory equipped with a full size 1600 tonne extrusion press. The Centre focuses on Doctoral and Post Doctoral research. At the 31st Metal Bulletin International Aluminium Conference in Madrid, 27-29 September 2016, Martin Jarrett of Constellium explained that this Centre enables them to undertake research without disrupting primary production. However, it is probably the flow of highly skilled Post Doctoral workers that Constellium value the most.[31]

Fig 1.19 Large format aluminium alloy extrusions in Constellium's plant, Singen, Germany

Fig 1.19 The first aluminium extrusion designed and realised by Professor Michael Stacey in just three weeks in 1984. To resolve the junction between the RVP Integrated Panel System designed by Stacey and Greenwood Airvac extruded aluminium louvers. The new interface extrusion was polyester powered coated black to effectively visually disappear, yet providing full wind and weather protection of the ICI *Cancer Drug Prototyping House and Factory* at ICI, Macclesfield Phase One, England, lead architect BDP (Manchester) building envelope cost in 1984 – £1.75million. The extrusion off-cut was re-photographed in 2017

The formal aims of the Centre stated at its outset are:

1. **Lightweight material design**: the development of a range of AA6xxx alloys with properties that exceed the present industry benchmark in terms of strength and formability;
2. **Corrosion resistance**: We believe that the new alloys, together with advanced die design that reduce and optimize wall thickness and integrate extruded sections with cast and pressed sheet components, will provide design solutions that will increase weight saving and vehicle productivity;
3. **Sustainability/Recycling**: to explore the increased use of process scrap and end-of-life scrap in alloy formation in order to minimise the use of primary metal, all without a significant degradation in properties;
4. **Joining, pre-treatment and vehicle integration**: to optimize the functionality of extruded sections for vehicle integration, including in-line surface pre-treatment and in-line fabrication, cutting, punching and bending.[32]

Paul Warton, President of Constellium's Automotive Structures and Industry business unit described his ambition for this research centre:

> *We expect the market for extrusions in automotive structures, power train and chassis applications to grow rapidly over the next five years and this represents a major business opportunity for Constellium. We believe the new Centre will enable us to exploit this growth by mastering the cutting-edge of automotive light metals research. Furthermore, because we are part of the Centre consortium, new developments will generally be carried out in close association with our strategic customer and supplier base to support the continued growth and evolution of our business.*[33]

Dr Roger Darlington, Research Manager at Jaguar Land Rover, considers:

> *Our work with the new Centre will give us a strategically significant opportunity to expand our capabilities across a number of different manufacturing disciplines, gaining both environmental and economic benefits through the development of new, highly efficient alloy processing and recycling techniques. Jaguar Land Rover is a leader in the application of lightweight premium vehicle architectures and the Centre's research programme will help us define*

Fig 1.21 An aluminium alloy chassis, comprising sheet, extrusions and castings, which is common to both of Tesla's current electric cars, 2017

and produce the high performance lightweight structures of the future. We will also be exploring how advanced alloys can help produce lighter and more efficient powertrains and chassis components. To help secure success, our work with the Centre will include close collaboration with key partners in our supply chain.[34]

It will be interesting to see as this research centre matures, which has now been up and running for around three years, whether it will expand into other fields of endeavour that can benefit from the well considered application of aluminium, namely architecture and the infrastructure of the built environment. In Prototyping Architecture (2013), the author wrote about the importance of one-to-one prototyping and testing to the advancement of architecture. In part having learnt in the 1980s that an aluminium extrusion was a means of turning an idea, into a drawing and subsequently into a component within less than three weeks.[35]

Lightweighting – a quiet revolution

A quiet revolution is underway in the fixing of lightweight aluminium structures stimulated by the interest in **lightweighting** and thus aluminium bodied car assemblies by mainstream vehicle producers such as Ford, Jaguar Land Rover and Tesla.

This in turn has stimulated the designers and suppliers to investigate means of fixing aluminium. Jaguar Land Rover, in all aluminium vehicles such as Range Roger 2013, use rivets and glue to form structural connections between aluminium components. Thus avoiding welding, with its associated risk of thermal distortion, health and safety concerns in the factory environment, and energy usage, by eliminating the need for fume extraction.

In the 1980s a Rivnut® was quite a sophisticated means of joining

Fig 1.22 Three layers of aluminium alloy sheet fixed with Henrob self pierce rivets (SPR)

aluminium components. This has now been replaced by a flow nut or flow drill, where the aluminium of the of the component to be joined itself is formed into a threaded receptor for a standard aluminium bolt, for example Flowdrill®, see www,flowdrill.com.

Fig 1.23 A Flowdrill port and aluminium bolt fixed through a small-extruded aluminium box section

Fig 1.24 A Tesla Model S 100D, electric car, on sale in a shopping mall in southern England, 2017

In some **monocoque** vehicle structures it is necessary to join three layers of aluminium sheet together. This can be achieved using a Henrob self pierce rivet (SPR). This is a cold process that can secure two or more sheets of aluminium without the rivet piercing the lowest sheet.[36] All of these fixing techniques are delivered in the factory by programmable industrial robots, which assemble body shells like a new industrial ballet, watched by their human supervisors of quality control.

Combined with new aluminium alloys these joining techniques generate a tremendous potential for new lightweight structures in architecture and infrastructure – a potential new generation of technology transfer for the twenty-first century.

Art and Aluminium

Fig 1.25 Aluminium Chaise Longue No. 313, designed by Marcel Breuer, 1932

Fig 1.26 The extruded aluminium armature of a WarHorse Puppet being dressed at the Royal National Theatre, London, England

TSC Book One: *Aluminium and Durability*, observed that the oldest extant aluminium used in architecture is the painted ceiling of the Church of St Edmund, King and Martyr, Fenny Bentley, Derbyshire, England installed in1895.[37] Some 40 years later the first use of aluminium in bridge building is the replacement decks of Smithfield Street Bridge, Pittsburgh, USA, in 1933.[38]

The architect and furniture designer, Marcel Breuer in *Architecture and Materials*, a chapter for *Circle* (1937), an art and architecture publication, suggested that: 'New materials, new possibilities, new constructions, new forms: these are the bases of a modern art of building.'[39] He continued these 'new materials are chromium, the different aluminium alloys, artificial silk, rubber, oil products, reinforced concrete, glasswool,...'[40] He looked forward to new possibilities: 'The modern movement utilizes these new materials. It tries to discover their laws without any aesthetic or technical prejudice.[41]

In 1932 Marcel Breuer had designed Chaise Longue No. 313, with a flexible (springy) frame of "Anticorodal" (Duralinium) alloy aluminium flats and varnished wooden slats with soft pad upholstery as an option. Marcel Breuer believed in the excellent qualities of aluminium: 'this new material, light weight and freedom from rust, will contribute towards the further development of metal furniture.'[42] The chaise was produced by Embru AG (Eisen-und-Metallbettenfabrik AG, Rüti) for Wohnbedarf AG, Zurich. Aluminium based chairs, stools and table of related designs by Marcel Breuer, were also produced by this company. In 1958 Charles and Ray Eames launched the Aluminium Group range of Chairs using cast aluminium components, for Herman Miller (still sold today by Vitra) as discussed in TSC Book Two *Aluminium Recyclability and Recycling*.[43]

> At the end of 1932, Marcel Breuer directed the modernization of a new shop in Talstrasse 11 for Wohnbedarf AG in Zurich, which had been founded in 1931 by, among others, the architectural critic, Sigfried Giedeon. The goal of Wohnbedarf AG was to develop, more or less as a distributer, contemporary furniture with a light appearance for apartments made in the New Building style in cooperation with designers and the industry. When the Alliance Aluminium Cie. announced the competition "Concours international du meilleur siège en aluminium" in Paris in 1933, Giedeon succeeded in establishing a second jury, parallel to that of industry representatives, with artistically oriented members, such as representatives of CIAM (Les Congrès Internationaux d'Architecture Moderne).[44]

Aluminium has in the late twentieth century become the first choice material for the assembly of stage and opera sets. The lightweight structures enable just two stagehands, typically dressed all in black, to change out surprisingly large elements. The armature or structure of the world famous WarHorse puppets, made by Handspring Puppet Company of South Africa, are fabricated from aluminium to be light in weight yet provide a stiff structure that enable the puppets to be readily articulated by the black clad puppeteers. The form of the horse is made of cane and the coat is represented by cloth, which is semi-internal to explicitly articulate it is a puppet.

Fig 1.27 Donald Judd, *Untitled*, 1969, silver anodised aluminium and Plexiglas (acrylic).

In fine art and sculpture, it was not until the 1960s that aluminium alloys, once again, start to emerge in galleries across the world, when it was considered an everyday or at least a familiar industrial material. The new extension of Tate Modern, designed by Herzog & de Meuron, opened in 2016. Originally it was called the Switch House but has been renamed the Blavatnick Building. Tate rehung its permanent collection for the opening, with one permanent gallery dedicated to new materials including aluminium, under the title *Between Object and Architecture*. The display includes

Fig 1.28 Tate Modern (Bankside Power Station): architect Sir Giles Gilbert Scott, 1963 and the Switch House: architect Herzog & de Meuron, 2016. The windows of the former Bankside Power Station are Gilbert Scott's familiar specification of anodised aluminium

work in aluminium by Marisa Merz, *Untitled (Living Sculpture)* (1966), fabricated from strips of aluminium, Mary Martin, *Inversions* (1966) aluminium, oil paint and wood and Donald Judd, *Untitled* (1969) silver anodised aluminium and Plexiglas (acrylic). The design of Donald Judd's work became increasingly rigorous and by the end of the 1960s he was in a position to define rectilinear shapes wit the upmost precision. This floor box is a superb example of sophistication in three-dimensional articulation reduced to its essence. Open on two sides, the box has an outer skin of anodised aluminium and an inner skin of Plexiglas, observes M. Stockebrand.[45]

The Turner Prize winning artist Wolfgang Tillmans was the subject of a dedicated exhibition at Tate Modern, simply entitled *Wolfgang Tillmans 2017*. This exhibition included a number of artworks that comprised photographs printed on aluminium, an exemplar is *paper drop Prinzessinnenstrasse*, Wolfgang Tillmans, 2014. Nineteenth century architects and critics, including Augustus Welby Northmore Pugin and John Ruskin, wrote passionately about truth to materials and this became a basic tenet of the Modern Movement and modernist architecture. However, the notion of how true a material can be has never been explored, some contemporary architects such as David Chipperfield circumvent this issue by talking about naked or self-finished materials. Wolfgang Tillmans is firmly part of the mimetic tradition, which stretches back to the era of Baroque architecture where wooden columns were painted to look like marble in the upper storeys of a church – evident in the Church of Saint Nicholas, Staré Město, Prague, architect Kilián Ignác Dientzenhofer, completed in 1737. Many specifiers prefer to see the material for itself, which explains the renewal of interest in the very durable and ravelling finish silver (or natural) anodising of aluminium components. However, the mimetic tradition remains part of humankind material culture.

Fig 1.29 *paper drop Prinzessinnenstrasse*, digital print on aluminium, Wolfgang Tillmans, 2014.

Notes

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Bees are the Sentinels of the Planet

This chapter primarily comprises a conversation between Wolfgang Buttress and Michael Stacey at the Hive in the Royal Botanical Gardens, Kew, on 31 October 2016, following the Towards Sustainable Cities Symposium.

Michael Stacey – Wolfgang what prompted your interest in Bees?

Wolfgang Buttress – My interest in Bees? I have known how important bees are for a long time, and more crucially, over the last three or four years I have been aware how bees are suffering and dying in unprecedented numbers. Bees are responsible for pollinating 30 per cent of all the food we eat; you can see them as sentinels for the planet, they have evolved for 120million years. The hive, the beehive, is a barometer for the health of the planet, the healthier the hive – the healthier the planet, sadly the reverse is true today. Tom Bennett, a co-worker at my studio, suggested that we should enter the competition to design the UK's Pavilion at the Milan World Expo, 2015. The Expo's theme was "feeding the planet" which is a laudable and amazing theme, but how do you express this in a pavilion that is 100m long by 20m wide? At first I was a little sceptical about the budget, not just for the pavilion, but also for the complete site. If I was going to do something, it needed to say something that is universal and would hopefully make a little bit of a difference. It needed to be as sustainable as possible and it needed to appeal to a four or five year old, as well as an academic, and it needed to be universal, to allow people

Fig 2.1 A beehive photogrpohed by Wolfgang Buttress

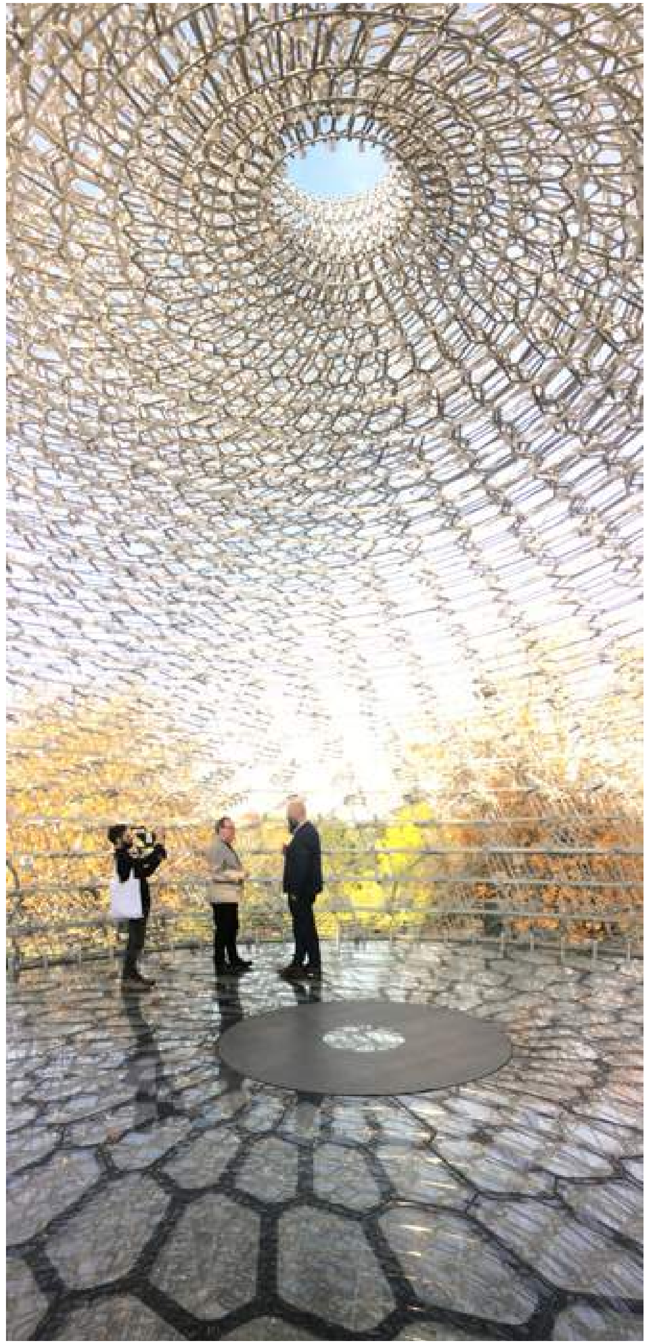


Fig 2.2 Wolfgang Buttress being i nterviewed by Professor Michael Stacey in the Hive, Kew Gardens, and filmed by William Victor Camilleri

from different cultures and with diverse languages to understand it.

There was a moment of serendipity, I was discussing bees as potentially being a great metaphor, when a friend said; 'If you are interested in bees, then you need to talk to Dr Martin Bencsik at Nottingham Trent University, who is undertaking incredible research on how bees communicate, not just with each other but also the human race.' So I went to Nottingham Trent University and for the first time donned a beekeepers costume. At first I was nervous, I thought I would be stung by 40, or maybe 50,000 bees. But the reverse was true. I opened a frame from the hive, and not only was it amazing to look at thousands of bees, what really struck me was the smell and the sound – a really deep visceral hum. There and then, I decided that if I was going to design a pavilion as a sculptural experience, it needed to be multisensory and highly immersive and go inside you. It should not be loud and preachy, but quiet and subtle.

Fig 2.3 The aluminium meshwiork of the Hive being assembled by Stage One in Milan, 2015

MS – If we now go on to the realisation of the Hive. Why did you use mill-finish aluminium to fabricate this structure?

WB – I was keen to be as sustainable as possible and to be as honest as possible – to let the material patinate with time. I was quite surprised that we used aluminium. My first choice was stainless steel, as I have worked a lot with stainless steel in the past. I had worked aluminium, but only cast aluminium and only small pieces with aluminium plate, nothing of this scale. Early on Tristan Simmons from Simmons Studio, the structural engineer, when the aim was to keep the structure as light and delicate as possible, he identified, that in stainless steel all the members would have been a lot heavier just because of the materials' self weight. I was keen that it should be as delicate and fine as possible, and as unprocessed as possible. The Expo was originally only planned to last six months and although I was keen that the Hive, the sculpture we are in today, would have a second life it was important to know that the aluminium could very readily be recycled. It would also have been easier and cheaper to weld everything on site, however, this would have limited the potential reuse of the Hive after the Expo, thus it was designed for disassembly (DfD). This was important to me from the beginning of the design process.

MS – Do you think aluminium can be described as sympathetic and powerful?

WB – I think it can. On a sunny day like to day, the Hive feels like part of nature. It is very much an intervention in this landscape. But it depends on how you use aluminium. Because there are 170,000 aluminium components surrounding us, it catches the light in many ways. It frames nature and even though it is artificial, it's a sculpture, to me it has repetition and it is visually porous – it sits sympathetically within the landscape.

In terms of power, aluminium is a metal and it comes from the earth and this connection is quite visceral. It was smelted and melted and comes to make something lightweight, which is like a gossamer. There is something very nice in the journey of the material from intense heat and process, to something that is feathery and delicate.

MS – Excellent. Is Richard Buckminster Fuller, and his emphasis on lightweight structures, a significant influence on your work?

WB – Massively, he is one of my heroes. In Belfast, a couple of years back, (2011) I did a sculpture, which is a pair of geodesic domes,

Fig 2.4 The Hive at the Royal Botanical Gardens, Kew, London, England 31 October 2016

one inside the other. What I admire about Buckminster Fuller's work is the relationship between form and structure and that there is no division between structure and aesthetics. There is no division, just harmony, reduced to the essence, a real purity and beauty. He was not trying to hide anything, the structure celebrates what it is. He was way ahead of his time.

Fig 2.5 Richard Buckminster Fuller's Montreal Biosphere, the United States' 1967 Expo Pavilion, photographed 2015

MS – Was collaboration key in the design and delivery of the Hive?

WB – Collaboration was essential. To get this project together involved Wolfgang Buttress Studio, BDP Architects, BDP Landscape Architects, Tristan Simmons Studio, Dr Martin Bencsik and the musician. In terms of the creative team, which I brought together, there was about 10 to 15 creatives and the engineers and fabricators, in total probably 250 to 300 people worked on this project. Even though it was a very simple idea, to actually realise something as complex as the Hive obviously needs a team, but it also needs a strong vision, it needs something very simple so that everyone understands it. What was life affirming for me, sometimes when you work with other creatives there can be issues in terms of ego, who is in control, who is not in control and what we all learnt from this project was letting go and how liberating letting go can be! As an artist you think that all the answers are inside yourself and you are expressing outwards. Sometimes the answers are out there, and you are just a conduit. For example with the soundscape, the music that you can hear now is a very gentle hum, you can hear the cello underneath and hear the violins and mellotron coming in, but it has a lots of space, as soon as you put too much in, as a human intervention, it gets muddy. It is the idea of trying to keep a harmony. The most important thing about the sculpture is the void, is the sphere, the nothing in the middle. That is as important or even more important than the structure itself. Trying to achieve harmony between space and non-space.

MS – Within your own studio, you mentioned the role of Tom Bennett, a University of Nottingham, MArch architecture graduate?

WB – Its all his fault! Tom started working with me about two and half years ago. I had a word with an architecture studio tutor, Nicole Porter, at The University of Nottingham, I was looking for someone who was very good at Rhino, as I was working on a bridge in Salford at the time, she recommended Tom and he has

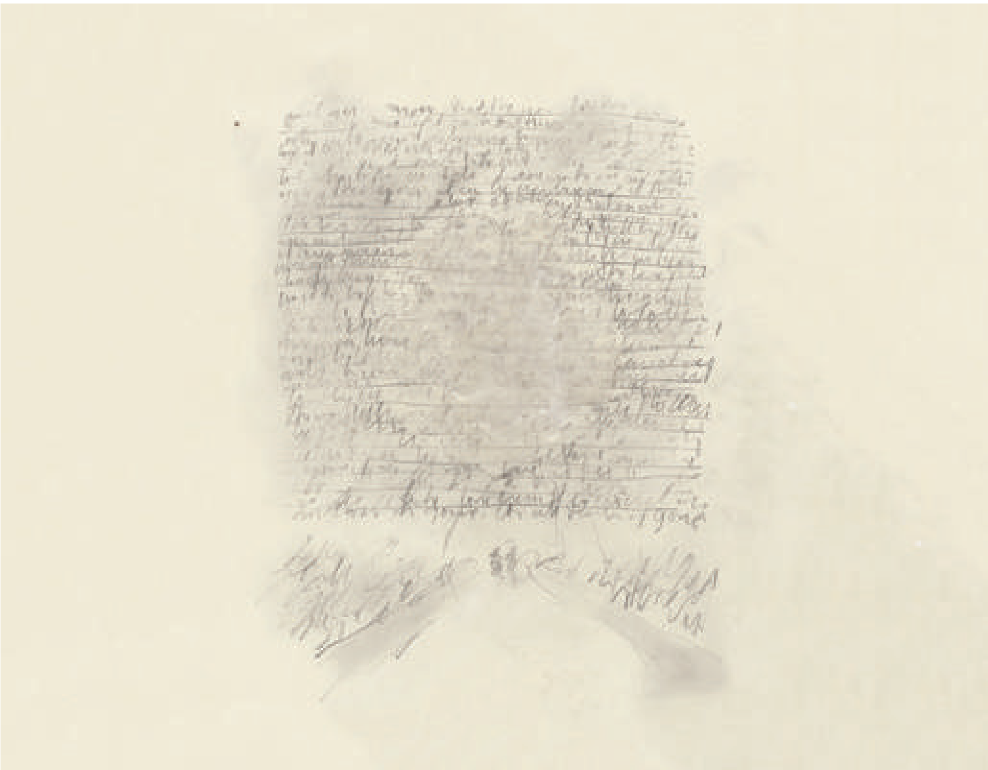


Fig 2.6 Wolfgang Buttress' early sketch of the Hive

Fig 2.7 Wolfgang Buttress' studio in Nottingham, England

been working with me ever since. In January 2014, Tom suggested that we apply to design the UK Pavilion at the Milan World Expo. At first I was quite sceptical. I am an artist first and foremost, I am not an architect, I am not engineer. The amount of people applying would be massive. The amount of work even to be shortlisted was

Fig 2.8 The Hive at the Royal Botanical Gardens, Kew, London, England 31 October 2016

so much, there was no fee involved and how do you address the theme of "feeding the planet" in a pavilion? So there were a lot of things conspiring against me. Until I got the idea! … Then sometimes when you get the idea, you have to follow it through. It seemed that the Hive was one of those projects where everything happened. We never had to push too hard, like pushing gently to open a door.

MS – So everything fell into place. But could you have done it without digital design and digital fabrication?

WB – No.

MS – But you started with a pencil sketch?

WB – Yes. Like all of my sculptures they start with an idea, the concept, and then I sketch it, which gives it its feel, its atmosphere. When I first set up my studio in Nottingham, 30 years ago, I made all of the sculptures myself, so I understand fabrication, I know how things are made. But as the sculptures have become larger and more complex it has been essential that I work with structural engineers from the outset. To achieve harmony between form, meaning and structure, it goes back to our earlier discussion of Buckminster Fuller. Right at the beginning Tristan Simmons was part of my team. Having sketched the Hive, I had the idea of an abstracted honeycomb, a layered structure. At certain vistas the whole piece would be porous and as you walk towards it would become denser and denser. I had this idea of how it would work, however, it is almost impossible to communicate this with a pencil sketch. You need to use digital software, my studio uses Rhino, the same as Tristan uses Rhino. So it was a process – an almost Darwinian iteration. The Hive was designed parametrically. We could make the pavilion larger, smaller, more nodes. less nodes… We would send this to Tristan, he would analyse it finding were the stresses were and where there were complications, where there were challenges, back and forth and back and forth. At first there were 170,000 different components, but each one was completely different. Theoretically it could have been built, however, we had such a short timescale, we only had a year to design, fabricate and install it. To have 170,000 different parts, the risk of error would have been crazy. We got it down to 200 different types. Again this could have only been achieved by using computers, by going back and forth, to find that sweet spot between chaos and what is structure, to find harmony between the two.

We drew, we made renders, and one-to-one prototypes, but because of its size and scale, and the way sculpture works in a landscape you never know 100 per cent what it looks and feels like until it is built. There was a moment in Milan, when first we used scaffolding as a structural prop, but this scaffolding acted as a veil and you couldn't see what was happening inside it. I remember the scaffolding coming down after two days and I was looking through my figures; fearing that the whole sculpture was going to sink, is it too dense, too porous, not porous enough. Thankfully I think it did OK.

MS – It was fabricated by Stage One, using laser cutting, water jet cutting, and machining?

WB – The only laser cutting we used was on the steel rolled ring beam. All the aluminium was waterjet cut, if we had used lasers that would have introduced heat into the aluminium, and would have made it 30 per cent less efficient – more expensive, more material and thus fatter.

MS – The aluminium would have lost strength in the heat-affected zones.

WB – Yes. Even though the waterjet cutting process was slightly more expensive, it meant that we could save money in the material we used. The waterjet cutting is incredibly accurate and it did not introduce any distortion and each piece is etched with its own part number, thus each layer has a code. So for the fabricators and the installers on site they knew what was happening, the Hive was assembled from a kit of parts.

MS – Comparing the Milan Expo 2015 and the setting here at Kew Gardens, 2016, which is the better context for this pavilion?

WB – A good question, Michael. I was so happy it was in Milan. Just that we made it, against all the odds. We had won the competition and delivered. It was an amazing feat, not just for me, but to bring art, architecture, landscape, science and music together.

MS – All representing the UK.

WB – In one simple idea, so that was a remarkable achievement. What was lovely in Milan was the sky, the incredible blue sky. But here at Kew, today, it does not look that different, again there is an incredible blue sky on this delightful autumn day. One of the qualities that is better here at Kew is that we knew what the context would be. Whereas in Milan, I had no idea who our neighbours would be, the only constant was the sky. Here we remodelled the earth so we knew the vantage points. Here at Kew you have a borrowed landscape, a peripheral vision. You look through the sculpture and it frames nature. In many ways it is more successful

Fig 2.9 Milan, 2015

Fig 2.10 Kew Gardens, 2016–2017

here, it seems to belong here at Kew.

The sounds you are hearing are triggered by a live beehive, here at Kew. Whereas in Milan the beehive was in Nottingham and everything was sent via the internet. Here it feels grounded. It presents itself quite subtly, although it is 17m tall, you get glimpses of the pavilion through the trees and this will change with the seasons. Now the leaves are starting to fall, it will look very different in the winter. The experience of visiting the Hive will vary in winter from the summer. I am very happy that it has a second life. It is the only UK Pavilion that has ever had a second life. The others have been scrapped or recycled. We achieved what we set out to do.

MS – It's an exemplar of design for disassembly (DfD) and reassembly.

WB – Exactly.

MS – The bees sound livelier? This is truly an immersive experience; it feels like I am interviewing Wolfgang Buttress and the Bees.

WB – The sun on the Hive here at Kew has stimulated their activity, which stimulates the soundscape.

MS – What is the future for the Hive will it become a permanent pavilion here at Kew Gardens?

WB – Well there are conversations about keeping the Hive here longer than originally envisaged, which was 18 months to two years. Visitor numbers to Kew Gardens are up to 40–45 per cent, since the Hive opened, which is amazing. 3.3million people visited the Hive in Milan, but only 2.5 per cent from the UK. Thus, to communicate the importance of bees to a UK audience is fantastic and in the setting of a 300 year old Royal Botanic Garden. [1]So I think it will stay here for a little will longer, but it was always designed to be taken apart and reassembled. Therefore in the future, in a few years time, it might be nice if went up North. It was conceived in the North and built in the North.

MS – In the North of England.

WB – It would be nice to for it to go North. But to me I am delighted it has a second home.

MS – Might the locations of the Hive be; Milan, London and Nottingham?

WB – The future will see.

MS – Thank you for taking part in the Towards Sustainable Cities Symposium? What in today's symposium will influence your future practice?

WB – The use of aluminium started for me on the Hive. Today talking about the benefits of using aluminium, in terms of how easily it can be recycled. I was surprised by how strong it is. The aluminium alloy use on the Hive (6082 TS) is as strong as stainless steel and it is so light. Just two people can pick up large sections and put it together. You do not need large cranes. There is something quite personal about this. You need less people. It is hands on. Its like making Meccano or Lego again. Even though one is dealing with very large sculptures and structures, it's a very hands on process.

Fig 2.11 The waterjet cut components of the Hive in Stage One's workshop in York, England

Fig 2.12 The Autum or Fall at Kew Gardens,2016, viewed from below the Hive

Some of the talks this morning were very interesting, especially second life, design and what materials can be used for. How to use them and why you should use them. This is central to my practice, and how I design, to be as efficient as possible. If one is laser cutting or waterjet cutting, we nest the components to create as little waste as possible. The challenge is to get the most out of the budget as possible. So that satisfies my creative intent and benefits the project.

MS – Thank you Wolfgang.

WB – It's a pleasure.

A detailed case study on the Hive designed by Wolfgang Buttress is included in TSC Book Four *Aluminium, Flexible and Light*.[2] The role of design for disassembly (DfD) in sustainable architecture and material stewardship is set out in *Aluminium, Recyclability and Recycling*.[3]

Experiencing the Hive, at Royal Botanical Gardens, Kew, London, England

The following are selected responses from architects, engineers, fabricators and finishers upon visiting the Hive in Royal Botanical Gardens, Kew, on 31 October 2016. The full interviews with these participants in the 2016 Towards Sustainable Cities Symposium can be found in Chapter Six.

"I think it is a triumph, it seems like it has come home. It's the perfect location for the Hive, being in this pavilion is completely immersive experientially and yet it communicates a very serious message, and it's very beautiful." Julia Barfield of Marks Barfield Architects.[4]

"I am really intrigued by the structure and the mill-finished aluminium and how it's going to live in this very organic atmosphere. It might encourage things to move in, it's a very occupiable space. I am also intrigued by the structure, as I don't think an architect would have designed it 'like that'. There is a freedom of being an artist where the edges are left unresolved. Had it been designed by architects, we would have frantically been worrying about the resolution of the geometry and what would happen at the edges." Jo Bacon, partner at Allies & Morrison

"I am very luck to live in Kew and I know Wolfgang. It's a really wonderful project. I think Wolfgang's achievement in getting it to Milan and now Kew is great, especially as a Kew resident. But as a structure and piece of engineering it's a very enjoyable thing to have in the area. The Hive is an admirable piece of work. A lot of care, consideration and thought has going into how to make something look very random but has an underlying rationality, which is nice to see when you look at it and try to understand it." Tim Lucas, Engineer and Partner in Price & Myers

"Well, it's lovely to see such an open and dynamic and loose structure that is quite plant like, in a funny kind of way. It is also reminiscent of a hive, with many hexagonal patterns coming together. It is an extraordinary experience, when architecture really works well it is almost a spiritual experience being in that space. I certainly felt that today. Jim Eyre, founding partner of WilkinsonEyre[5]

"The Hive exemplifies a deliberately unstable, open boundary, defined by delicacy and resonance – perhaps the very antithesis of the firmitas that has defined Western architecture since Vitruvius uttered his famous paradigm. Monumental scale is achieved by aggregating small-scale elements using simple progressive gradients of progressively shifting dimensions made possible by contemporary parametrics and digital machining." Professor Philip Beesley of Philip Beesley Architects and the University of Waterloo, School of Architecture[6]

"The Hive is delightful and peaceful. The use of aluminium combined with nature is inspiring." Mo Panam, Joint Managing Director of Barley Chalu

"Beautiful, for me it is a mixture of hard architecture, science and nature, and engineering, focused on the flight of the honeybee. It's a beautiful project and I was delighted to meet the artist." Alex de la Chevrotière, CEO of the MAADI Group

Fig 2.13 The Hive at the Royal Botanical Gardens, Kew, London, England 31 October 2016

Notes

1 The origins of Kew Gardens date back to the exotic gardens established there in the seventieth century by Henry Capell, 1st Baron Capell of Tewkesbury. The Royal Botanical Gardens at Kew were established in 1840.

2 M. Stacey (2016) *Aluminium, Flexible and Light: Towards Sustainable Cities*, Cwningen Press, Llundain, pp. 134 – 151. For a monograph on the Hive see – W. Buttress Studio, ed., (2015), *BE · Hive: UK Pavilion Milan Expo 2015*, Wolfgang Buttress Studio, Nottingham.

3 M. Stacey (2015) *Aluminium, Recyclability and Recycling: Towards Sustainable Cities*, Cwningen Press, Llundain.

4 Mark Barfield Architects' projects include the Tree Top Walk at Kew Gardens, 2008.

5 WilkinsonEyre's projects include the Davies Alpine House and The Wolfson Wing of Jodrell Laboratories, both at Kew Gardens and completed in 2006.

6 Philip Beesley's reflections on the Hive from M. Stacey (2016) *Aluminium, Flexible and Light: Towards Sustainable Cities*, Cwningen Press,Llundain, p. 146.

THREE

Research and Architecture

Having the ability to inform design and realisation of architecture by accumulating a depth of knowledge, which stretches across many fields from social anthropology to material science, is and always has been an essential part of architectural practice. Research, undertaken both as a standalone, if typically, a collaborative activity, and research for a specific work of architecture, forms the core and cutting edge of contemporary architectural practice.

This chapter is based on a discussion between Stephen Kieran, James Timberlake, Billie Faircloth and the author, at KieranTimberlake's studio in Philadelphia, during the Fall of 2016.

Michael Stacey – James and Stephen when did you found KieranTimberlake?

Stephen Kieran – 18 July 1984.

Fig 3.1 Interview at KieranTimberlake's studio, Philadelphia, Fall 2016 with James Timberlake, Stephen Kieran and Billie Faircloth

MS – Why Philadelphia?

SK – It's our city, it's where we went to school, where we studied architecture.

MS – When did you establish a research group?

James Timberlake – Almost immediately. In the 1980s some of the work that Steve (Stephen Kieran is known to his colleagues as Steve) and I undertook was urbanism, tackling urban problems. We were researching the relationships between suburbs and central cities. The practice also undertook materials research at this stage. We formally established a research group in late 1999–2000. Out of this initiative Steve and I, in 2001, won the inaugural AIA Benjamin Latrobe Research Scholarship, which formed the basis for *refabricating Architecture* (2003).[1]

MS – Is it unusual for a US architectural practice to have a research group?

Billie Faircloth – It's unusual for a practice to base their approach and way of designing on searching and searching again, KieranTimberlake embraces research as a design philosophy and a mode of practice. I believe this is unusual.

MS – Do you have a declared percentage of turnover dedicated to research? Or is that a commercial secret?

JT – No. We use a rough figure of between three and seven per cent of gross profits that are turned back into salaries, materials, fabrication and resources deicated to research both on and off projects.

MS – The complete research endeavour.

JT – We used the precedent of manufacturing and corporate industries, who use this approach. When Steve and I wrote *refabricating Architecture* (2003) that was one of the revelations; the automobile industry, the aerospace industry and related industries were taking some of their profits and instead of taking them home, were turning them back into generating new initiatives within the business. We realised that architects and engineers were not doing this. This appears to be one of the great failings of architecture and engineering.

MS – Thus your own research informed the policy of the practice.

SK – Exactly.

MS – What combination of your in-house research is working on

KieranTimberlake's architecture projects and working on external research projects such as the collaboration with my practice on the Towards Sustainable Cities research programme?

SK – It varies, dependent on circumstance. The core of the research work remains practice driven. Research is built into the dynamic of how we design. We are inquisitive architects who ask questions as we design. We need research to find the answers. This forms the core, and out of this endeavour comes relationships with manufacturers of products, with material producers and systems specialists. From this research we establish relationships and typically the research starts to move beyond projects. For example, people like you, with whom we have worked with in other contexts, approach us directly with a research project.

JT – I see it three ways: empirical research; research with design and design with research. Each of these has varying design increments with them or non at all. We are an architectural firm and design comes first. The research is there to advance and inform design.

BF – What you would find if you went out into our office and asked someone what they were working on? They would respond that 'I have been working on this question for some time.' That person may be working on an architectural project, but in fact they are pursuing a specific kind of query, they are pursuing a specific type of information that they are working with. It's not just that we have a research group, we set up the research infrastructure to be inclusive and accessible to everyone here, it is part of how we engage design.

MS – It's an integrated model.

BF – Yes, it's totally integrated, Michael.

MS – Do you use the term *design research*? Do you see the process of design itself as research, or in your model is research supporting the design process?

BF – You are asking about the definition of research?

MS – In essence?

JT and SK – It's all the above. Both and.

MS – Would you describe yourselves as practitioner-researchers as defined by Steven Groák in *The Idea of Building* (1992)? He was very interested in the state of constructional technology in the 1980s and 1990s, as there had been many building failures in this period. He suggests that you must treat all projects as innovative, because the construction industry is inherently unstable.

JT – It was an important book that we read whilst writing *refabricating Architecture*.

MS – Steven Groák cited Alan Brookes and I as examples of practitioners who had a sustained commitment to research, which parallels your own experience, and this is probably more important than the term itself.

JT – This is the field of endeavour that is continuously evolving with only a few fixed points. One orthodoxy is empirical research and there is a body of work that accompanies this. However, when thinking about design with research and research with design this is continuously evolving, and our practice strives to be at the vanguard of evolving it. Because we are presented with different problems, each and every time we ask a question.

SK – Most of our research comes from a birth in design, in trying to make something, and solve a problem in the real world for a client.

MS – That suggests most of your research is project based and thus the questions are situated rather than abstract?

SK – It is typical of our practice that there are situated questions and situational questions that arise form specific circumstances that we need deep answers to, and thus deeper enquiry is required to design in ways that are provocative and innovative, solving problems. Sometimes the specific issues broaden out into research topics that are connected to the profession at large, an example is Tally®.[2] It started as an answer to a specific question. 'How much carbon is there in this building?' We did it after the fact. We figured it out. But someone said 'that did not do us a lot of good as we have already done the damage, so to speak, the building is up, it's there.' At a point like that the research moves into a different realm and becomes proactive, not only for our work but for the profession at large. Things begin in lots of different ways and then grow 'lives' of their own and go way beyond the specific project. Others are very specific questions that we answer, we use to design and move on.

MS – You have touched on my next question. KieranTimberlake is an early adopter of **Building Information Modelling (BIM),** the inventors of Tally® and practitioners of life cycle assessments. What drives this pursuit of new methods of working?

BF – Often what drives the pursuit of new methods of working, on a day-by-day basis is the kind of questions we are wrestling with.

Fig 3.2 Refabricating Architecture, Stephen Kieran and James Timberlake, 2003

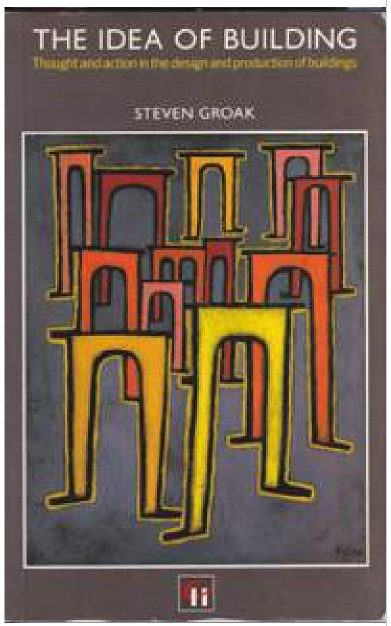


Fig 3.3 The Idea of Building, Steven Groák, 1992

In our practice there is absolute awareness of the questions that our profession should be collectively wrestling with, alongside the aspirations that we have for our projects. So, we are constantly investigating, through the kinds of questions we ask and the projects we undertake, what are the best tools, the right platforms, the best means of expressing and placing information to pursue a project. Most of that is driven by a real desire to engage innovation in a smart and purposeful way.

MS – Is part of your aim to inform the built environment of North America?

BF – Life cycle assessments is a very particular method and practice and it basically says we are going to try and understand the way our decisions about the kind of materials we are designing with equal a certain amount of environmental impact. Life cycle assessments allow us to measure the environmental impact of our decisions.

MS – So you are quantifying your decision-making process.

JT – Billie has described a component of our thinking. Beginning back in 1984, what has driven this firm from day one, is the fact that in order for architecture to evolve and change we have to think about new ways, new processes, new modes of delivery, new ways of integrating thinking, new ways of working – a process of continuously evolving. This has been mapped, if you follow the arc of our practice, we are always trying to think five, ten, even 15 years ahead. That was the thinking behind *refabricating Architecture*. In 1984 Steve and I *knew*, coming out of Graduate School and having worked, we were still using Maylines® and triangles. Computers may have been a nascent thing, but were primarily used for computation only.[3] As the practice has evolved, so has the technology that under pins it, BIM, data acquisition and data analysis, data usage, data generation – we are developing software like Tally® and Pointerlist™ in order to help evolve the tools and products we are generating.[4] We are constantly thinking about where we are going to be five years down the road, where are we going to be ten years or 15 years down the road and what do we need to be working on and thinking about in order to be part of the vanguard of a new future, informing the built environment of North America. That translates into the day-to-day challenge of finding the best tools to get the work done, including prototyping for example, which is a big part of this firm.[5] As an ISO certified firm,[6] failing early and failing fast, is key. Not just prototyping the first time out with our clients but doing it here in the office.

Fig 3.4 Plastics Now, Billie Faircloth, 2015

Fig 3.5 Melvin J. Claire Levine Hall, Philadelphia, USA, architect KieranTimberlake, 2003

MS – James, you have referred to *refabricating Architecture*, which you and Stephen wrote and published in 2003. This book envisaged prefabricated houses possibly made by a corporation, such as Boeing. In the past 13 years has your vision changed? Has the Loblolly House (2006) changed that vision? Or is this a future you are still working on?

SK – We still think it is a valid vision and one that is very much on the way. We may see it first more fully realised in the developing world, rather than in the already developed word. In part, due to the scale of markets and the pervasiveness in the problem of the lack of adequate housing and the urgency of this need. However, we have plenty of evidence in the developing world of large-scale organisations being formed along the lines suggested in the last chapter of *refabricating Architecture*, which, in essence, proposed the repurposing of an abandoned Boeing plant. Thus, the prospect is still out there. In the meanwhile, the construction industry has taken up ideas from *refabricating Architecture* in incremental ways. There is a lot more component-based assembly off-site, across the board, in all aspects of design and construction, there are large amounts of mechanical implementation of off-site, in larger scale assemblies that are brought to site and put into position, with lots of the fabrication being undertaken off-site. Things like unitised curtain walls, which in 2003 in the USA were quite a rarity, are now quite commonplace. We think the industry

Fig 3.6 Loblloly House, Maryland, USA, architect KieranTimberlake, 2006 in general is moving in the direction proposed in *refabricating Architecture*.

JT – I think that the factors that have evolved over the past 12 to 14 years since *refabricating Architecture* are two-fold: one the economy took a dip and stopped the construction industry – it shook a lot of the construction industry and it had to restart again. Secondly, two other critical technologies have emerged in this time period that are beginning to provide other streams of production: robotics and printing. There are many initiatives in printing buildings and components for buildings and there is the application of robotics, which has enabled chunks and increments of buildings to be built rapidly, particularly in difficult situations. This has encouraged architects and engineers to consider off-site fabrication and the chunking of buildings.

MS – What part has aluminium played in the architecture of KieranTimberlake?

SK – A seminal use of aluminium for us has been as framing, forming the primary structure of projects. We first used it on the SmartWrap Pavilion at the Cooper Hewitt, Smithsonian Design Museum, in 2003. [Turning to JT] I remember we were standing in the garden of the museum and saying we could make a building out of this. We had an opportunity with the Loblolly House to do that. We thought of aluminium in this form, as it's a great material, it's a scaffold, a frame that can be readily assembled and rapidly dissembled. Ultimately it can be fully recycled, if necessary. Following on from that experiment, a couple of years later we designed and assembled the Cellophane House at the museum of Modern Art, in New York, as part of the Home Delivery exhibition (2008). We took on how high we could go using an aluminium framework structure. Including the roof terrace, this is a five-storey dwelling, made of an aluminium scaffold system. This is one stream of KieranTimberlake's experimentations and research. It had a lot of motivations including the ability to reclaim and reuse it without even having to change it into a different form, scaffolds are used all over the world, for all kinds of things. We found this to be very potent.

MS – Did you find the Bosch Rexroth aluminium extrusions of this 'scaffolding' while undertaking the research behind *refabricating Architecture*, as this system of extrusions is used in manufacturing industries?

SK – No, my recollection is that we were looking for a scaffold system about which we could deploy SmartWrap, a mass

Fig 3.7 The extruded aluminium frame of the Loblolly House, Maryland, USA, architect KieranTimberlake, 2006

customised printed building envelope, for the Cooper Hewitt. We considered all kinds of scaffold systems and found the Bosch Rexroth aluminium extrusions in that search.

JT – It was beautiful, it was machined, it was elegant, it was precise, it gave us a lot of ability to configure and kit this pavilion. It had a lot of flexibility in terms of what we could do with it.

MS – It would appear that my post rationalisation is wrong, because Bosch Rexroth sections are used to make mass production lines.

JT/SK - Absolutely.

MS - I thought it was a research spin off, from book, pavilion to a house.

SK - When we were doing the research for *refabricating Architecture* and we went into industrial plants, we certainly saw this system of aluminium extrusions: as equipment enclosures, for protection and for the support of equipment. We were familiar with this system, however, we did not at that point think about using these components to make architecture. That took a couple of further steps together.

MS – I noticed that you are defining the spaces of your excellent workshop, downstairs, with the same system.

SK – That was part of Cellophane House.

MS – So, that is creative reuse.

SK – Absolutely.

MS – Design for disassembly (DfD) is very important, the potential of reconfiguration and reuse, and ultimately the potential of recycling. This returns our conversation to life cycle assessments and the need to quantify the embodied impacts of a work of architecture or building might have, which is why KieranTimberlake has developed Tally® for use alongside Revit® (BIM software) with key partners. Billie could you explain this?

BF – The partners in the Tally® software are Autodesk and Thinkstep. Autodesk are the authors of Revit® and Thinkstep is the provider of life cycle assessment software, GaBi®. Both are experts in their own realms. It is interesting to note that our initial experiments with life cycle assessments started with the Loblolly House and the Cellophane House, because of the premise provided by Steve that one day he wanted to go back to the site and return it to its original condition. This provocation is recorded in the Loblolly book and this is design for disassembly.[7] We decided to take up this challenge and what would a design for disassembly specification look like for this house? How do we actually take it apart? We knew in taking it apart we would be able to quantify recovery. The only thing at the time was to associate the amount of materials recovered with how much embodied energy was recovered, because that was the best database we had at the time. Moving forward we decided to shift the conversation from embodied energy to embodied environmental impacts. We undertook a virtual disassembly of the Loblolly House and an actual disassembly of the Cellophane House and we then decided to move these assessments, in their entirety, into the design process. So that such assessments could be undertaken before anything is built or constructed. Our partners have worked with us to help develop a robust database of embodied environmental impacts, which enabled us to quantify: eutrophication, acidification, ozone depletion, global warming potential and embodied carbon. Our partners at Autodesk have enabled us to link Revit® with this database via an application-programming interface (API) in real time and vitally during the design process.

SK – There was an interesting discovery process along the way. We became interested in componentised assemblies as a way of enhancing quality, control and speed of construction. At the outset we were not thinking that if things are componentised and are bolted together they could also be taken apart readily, without having to pulverise a building, which is basically how most buildings are demolished today. Or they are 'let go' and nature pulverises them over time. A little bit later it became clear to us that we could reverse the assembly process and ultimately if you care about carbon and you are counting the carbon, you can give components and buildings an extended life by designing for disassembly. Most buildings can outlive their real estate timescale. It is where they are, the location that becomes the problem, not that the physical degradation means that they cease to exist. Design for disassembly is a way confronting this pervasive worldwide problem. It generates carbon currency, so to speak, for free by just moving buildings and infrastructure around, rather than pulverising them every time. Current geo-political circumstances and real estate circumstances forces us to abandon conventional buildings.

JT – It is a broader theoretical or philosophical question. What do we do with the resources that we have on this earth? And how are we deploying them? Buildings take up a considerable amount of global resources. We have come to the realisation and part of our profession, but not all, has come to the realisation that we need to do a better job of thinking about the future deployment of materials and the harvesting of resources and how they are employed. Tally® and its life cycle assessment capability goes a long way in that direction by providing real time embodied impact data to facilitate being able to make the best possible design decision.

We are only just scratching the surface of this problem, at this point in time. By the time Steve and I are long gone, by the year 2052 or 2055, when we have become carbon, we have returned to the earth, hopefully by then collectively humankind with be thinking about the kinds of materials we are utilising and how we are employing them. Right now, there is a rapid take off of all kinds of materials that architects want to innovate with, they want to be the first to use, but they may be the worst possible things to be utilising, to be building with, because they can't be used over and over again or can't be disassembled. These architects may get great bang for their buck visually the first time around, but downstream, four years or 100 years from now, they may prove to be horrible to maintain and poor in terms environmental resource and return.

BF – In our conversations during the time KieranTimberlake collaborated with Michael Stacey Architects on *Aluminium and Life Cycle Thinking* and in the discussion we had at the Kew Gardens Symposium with the International Aluminium Institute (IAI), we could see this problem is bigger than ourselves. In other words, when we engage with life cycle assessment, we present all the stages of the life cycle assessment of a material. Architects begin to understand that they are complicit across all of the stages; this is a value chain supply chain discourse that we need to be part of. This is key to moving the agenda forward and it is absolutely a multi-generational agenda.

MS – This needs to be done in fine detail, literally down to the nuts and bolts.

BF – We observed this in the way the nuts and bolts were key in the discussion with the members of the IAI. There are fine details that need to be discussed. One of the key issues for aluminium is the energy resources used to **win** (extract and process) this material; there are vast differences between using coal and hydroelectric energy.

MS – The power mix is important and in the near future we may well be specifying aluminium on a regional basis rather than using a generalised embodied energy figure that also tends to be about

20 years out of date. Such figures did not embrace new energy efficiencies measured in smelting technologies, for example. China uses mostly coal-based energy, the Middle East mostly natural gas and Norway and Canada predominately use hydro electrical energy.

BF – Our agency comes from specifying materials, but also being in the position to ask for chain of custody certification. This is one element of the kind of decision making we engage with when we are trying to determine how to precede with a project and which materials to use. We need high quality environmental data ‘on the table’ when making these kinds of decisions.

MS – Some architects seem to be surprised by the level of detail required in a life cycle assessment (LCA). Do you find that?

JT – I don’t think it is surprise. Many architects believe it is for someone else to figure out, that they were taught to design and to assemble and taught to conceptualise and that these other matters are not an act of design. When one of the things KieranTimberlake has suggested is that LCA is an act of design and design professionals need to engage with this toolset.

SK – The aluminium example is perfect, in this sense, if the design professions decided they were only going to specify aluminium that comes from hydroelectric energy sources, it would change where smelters of aluminium are located. This is an ethical stance that one could take.

JT – Compare that to doing it in the wrong place with the wrong carbon source and shipping across the world. Compare using hydroelectric energy and the impacts of shipping, with smelting aluminium on a regional basis with a ‘nasty’ carbon resource. Those are the comparisons that need to be made to make informed choices. There is another choice that needs to be made, which is whether some materials have a long-term place in the life cycle of design. Whether or not we should even be entertaining some materials for certain scales of application when they are evaluated on a holistic basis.

SK – I think the problem right now is that it appears to be overwhelming to designers to think holistically about materials, including the full material life cycle. The consequence for most designers is that they are going to limit their realm of influence to a much narrower range of choices, that are not necessarily well informed. We are rapidly coming to a time when that is no longer acceptable. It is not ethically acceptable to narrow down

Fig 3.8 Aluminium and Life Cycle Thinking: Towards Sustainable Cities, Stephanie Carlisle, Efrie Friedlander and Billie Faircloth, 2015

complexity because you can’t deal with it.

JT – The title of a ‘green’ book could be *The Holistic Obligation*.

SK – Think about the complexity. How much concrete goes into the foundation of a building, how much does that weigh and what is the environmental profile of the mix. How could you change that by making different decisions about structure and about every other component? Should one be focussing on weight, for example on how much things weigh. We now have the tools within our reach to design in an informed way. But it is one more thing for an architect to put into their whole mind set and set of obligations. This is what we are ethically challenged with by managing and manipulating in the world.

Getting people over that mind set of ‘I can’t handle the complexity’, through easy to use tools that are now to hand. Tally® is an example and Pointelist™ another example there are thousands of tools available and tool kits to use to inform judgements, to make deeper, more resistant and ethical judgements about materials and systems.

MS – Michael Stacey Architects used Revit® and Tally® to assess the impact of using aluminium formwork to cast in-situ concrete.[8]

BF – How was that?

MS – It went very well. However, we were able to email and Skype KieranTimberlake for advice, as we are collaborators on this research.

BF – To help primarily with interpretation?

MS – Especially interpretation. We were carrying out a multi-use application of Tally®, therefore we went straight to a process case rather than a building. We sought to compare the use of timber formwork and aluminium formwork. We compared the one-off use of timber formwork, which was the norm in the twentieth century, with the current-norm in North America of ten-times re-use, with some wastage. An aluminium formwork, however, can be reused many times for casting concrete - and we used a conservative figure of 250 times. Some suppliers would take that up to 300 or 350 times. We got to a fair comparison in pretty short order.

Some of the credit should go to Michael Ramwell in our team, a bright graduate of The University of Nottingham School of Architecture. We found Tally® very useable. However, we did warm up by spending about one year discussing life cycle assessments (LCA) in the context of recyclable materials, with KieranTimberlake.

Personally, I did the background reading on LCA largely from the books and peer reviewed papers you recommended Billie.

BF – You also demonstrated much of what James and Steve have just reiterated that as an architect and designer you are carrying around these questions in your head. Many designers are, but the issue is legitimising and articulating them, and then actually being able to take the next step to get through the complexity to answer these questions. Fortunately, right now, it is possible to work towards informed answers.

JT – In the future of this complex world, one place that architecture could lead is thinking about how to simplify the future, making it less complex - where innovation is defined as 'continuous new discoveries' and invention as the deployment of those new discoveries. When Steve and I were writing *refabricating Architecture,* we charted the development of materials over the centuries, this remained flat until the 1920s, when it started to rise almost vertically and now there are new materials discovered almost everyday. Architects generally desire to be in the forefront of deploying that, because it is seen as new and innovative. We, as a profession, might do better by thinking about how to reduce the palette of materials that we are working with and how to combine these materials - tying that to LCA and to a holistic model of integration, deconstruction and repurposing. Thinking about how best to partner some of the resources that we have, while employing the best practices of the new tools we continue to discover.

Technology can continue to role on, but we are rapidly running off the cliff in the deployment of new materials. It is fascinating to me that, as a profession, we may need to stop and take stock of what we have and employ that in the best way we know how. This could form a progressive yet prudent approach to the realisation of architecture.

MS – Is it important to you that 75 per cent of all the aluminium produced since 1886 is still in use or available for use by humankind?

JT – It's very important. It's important that steel is recycled, and that glass can be recycled. But the materials that we are taking out of the earth, like rock and stone, which we have found to be decorative in the past and that we have used in buildings, do not have continuous re-streaming. They might have a second life and then end up as ballast in our roads or under our pavements. We need to think about the carbon future of plastics and petroleum-based products, some of which have an on going recycling stream, but others do not. We need to think about natural fibres and how they might best be deployed and materials we can regenerate.

Fig 3.9 The new American Embassy,London, England, architect KieranTimberlake, 2017

The shipping of materials around the world needs to be reviewed; we, the profession, have placed artificial barriers on not shipping materials more than 500 miles under certain standards, for example LEED. It's a false complexity we have added, because it makes us feel good. There is a petroleum component to the shipment, but this may not be the key box we have to check off.

MS – Moving on. You are developing a wireless sensor system, which reminds me of late nineteenth century painting, as it is called Pointelist™?

BF – Yes, but it is called Pointelist™ rather than the art movement you reference, Pointillism, pioneered by Seurat and Signac.[9]

SK – However, the commonality with the art movement is that it delivers data about conditions, temperature, humidity and all kind of other things on a point basis, rather than the broad collection data of ambient temperature, for example. Underlying this is the fundamental premise that we can, by working with microclimatic data, optimise building systems to a level of detail that facilitates both comfort and energy performance. This is something that we can't do today with more globally sourced data, which we all know is not accurate for a place and a time. It is generalised data. That is the fundamental mind shift. The optimisation of microclimates is one of the next frontiers in energy management, for very specific climates.

Earlier today we were talking about how American buildings are run and managed. For the most part, when it comes to air conditioning, you figure out who is the hottest person and use this to determine what temperature do you need to cool the building to – to make the hottest person comfortable so that no one complains and then everyone else adapts via additional layers of clothing. Is there another way to go about that equation that could consider specific individuals and specific places in the microclimate of a building? The temperature where we are sitting, in this office, is quite different from where there is direct sunlight. That is the fundamental underlying premise for using micro-scale data.

MS – Stephen or Billie would you extend that into managing the use of air conditioning and heating with the seasons? It's the Fall, and during my visit to Canada and the US many buildings are still being cooled by air conditioning systems when the temperature outside is dropping quite rapidly, they are in the wrong mode consuming energy to create discomfort rather than comfort. Is this a common problem and will your point-based sensor system help with this dilemma?

BF – We assume that we must design for total ambient conditions, when in fact we are usually uncomfortable in the space each person occupies. This refers to the thermal comfort application of Pointerlist™. Pointerlist™, as a product, is a set of tools you could use as a designer, it presumes that we haven't got the kind of data we need from sensors. The data we actually need is highly granular. It is likely, given an academic budget, you could afford one kit of sensors, this includes a node and maybe five sensors to measure temperature in a space like this. In this office space, which happens to be a converted brewery bottling plant, we can see that five sensors are not going to tell a lot about what is really happening in terms of temperature profile across this space. The premise behind Pointerlist™ is that you can generate highly granular data sets based on the questions you are asking, be that about the scale of a major space like an office, or your need to measure temperature at the scale of an individual person.

Highly granular low-cost sensors, in our deployment, feedback an understanding of the modes which we are operating this building. We can analyse the interior data we are collecting, together with data from an exterior weather station that has been set up on the building. This data will inform the way in which we operate the building, either by flushing, using fans or turning on the chillers. The deployment of sensors gives us much more control, rather than making assumptions or taking our hands off the running of the building itself.

MS – That is partly because the weather is dynamic, and people are dynamic, whereas until recently our tools have been essentially static, a static Δ**T** an assumption of constant conditions. (Were ΔT when applied to construction is the temperature difference across a building fabric, the difference between the internal temperature and external temperature.)

BF – Past assumptions were based on homogeneous conditions throughout, whereas we know that we live in a world of heterogeneity.

SK – A few degrees makes a big difference. If you can raise the typical temperature, for instance, when cooling an office building and the people are still comfortable, this saves lots of energy. Through information you can better manage comfort conditions whilst using less energy.

MS – Is Pointelist™ is a future product? Will we be able to use it soon?

BF – Pointrlist™ is a product that we have been developing for over four years. Right now, it is being tested by over 25 architects, academics and researchers, who have things they want to measure. It's in a beta testing stage and some of the testers are tackling buildings and building environment, some are tackling materials, and some are tackling totally different challenges.

MS – KieranTimberlake is an exemplar of best practice, because you publish your research and experience in practice for others in our professions to consider. You appear to be very outgoing as a practice.

SK – We are not hermetic.

BF – We want to share with all whom are concerned with the built environment, including the complete supply chain, to inform the future of the built environment.

Fig 3.10 James Timberlake takes timeout from TSC field research to give an interview to the British media

Notes

1 S. Kieran and J. Timberlake, (2003) *refabricating Architecture*, McGraw-Hill, New York.
2 For more information on Tally® see choosetally.com (accessed January 2017).
3 AutoCAD® was released in December 1982, as discussed in M. Stacey (2012), *Digital Craft in the Making of Architecture*, in B. Sheil, ed., *Manufacturing the Bespoke - The Making and Prototyping of Architecture*, Wiley, Chichester, p. 70.
4 Pointerlist® is a new product being developed by KieranTimberlake comprising low cost wireless sensor for data collection, which is discussed at the end of this chapter.
5 See for example the Loblolly House prototype by KieranTimberlake in M. Stacey, (2013) *Prototyping Architecture*, Riverside Architectural Press, Waterloo, pp. 164–167.
6 KieranTimberlake is ISO 9001:2008 certified for the research, management, and delivery of architectural services; www.kierantimberlake.com, accessed December 2016.
7 S. Kieran and J. Timberlake, eds., (2008) *Loblolly House: Elements of a New Architecture*, Princeton Architectural Press, New York.
8 M. Stacey, (2016) *Aluminium Flexible and Light: Towards Sustainable Cities*, Cwningen Press, Llundain, pp. 330–352.
9 For more information on Pointelist™ see pointelist.com (accessed January 2017)

Fig 3.11 The Loblolly House prototype being assembled at the Prototyping Architecture exhibition, Nottingham

A building that sings for all of us – the National Museum of African American History & Culture

Washington D. C. was founded in 1790 following the Declaration of Independence from Great Britain by the thirteen American colonies in 1776 and the defeat of the British in the American War of Independence (1775-1783). The Declaration was made in Philadelphia, which initially became the capital of The United States of America, while Washington was under construction.

The capital is situated along the Potomac River, in the southern part of the United States below the Mason-Dixon line. This was in essence a political compromise, whereby the southern states agreed to the payment of war debts of $22million in exchange for the capital being founded there. The District of Columbia, more commonly known as Washington D. C., was formed by donations of land from Maryland and Virginia.

President George Washington selected the precise location of the capital. He commissioned the French artist and engineer Major Pierre Charles L'Enfant to layout the new city. At its core this plan established a grand avenue, a one-mile long and 400-foot wide swarth of green, which is now the National Mall. The essence of L'Enfant's plan was retained, even after he was sacked by President Washington in 1792 and replaced by American surveyor Andrew Ellicott.[1]

The Smithsonian National Museum of African American History & Culture (NMAAHC) has been built on the last remaining site on the National Mall and completed in the Fall of 2016.[2] 'It has been over a hundred years since such a monument was first proposed by black Civil War [1861–1865] veterans and 13 years since President George W. Bush signed legislation to build it, following decades of lobbying,' observes Josephine Minutillo.[3] The design of NMAAHC was won in an international competition in April 2009 by a team lead by David Adjaye, comprising Philip Freelon, Max Bond Jr. and SmithGroupJJR. The project was coordinated via a shared BIM and construction commenced in February 2012.[4]

The NMAAHC has a symbolic presence on the National Mall and Adjaye's design unites the content, the architecture and context of the museum. The client describes the museum as 'the American story told through the lens of African American history and culture'.[5] Yinka Shonibare described his response on visiting 'as I went through the building I went through a range of emotions: I was sad, I cried, I laughed. I was excited and I thought that was extremely powerful.'[6] Adjaye describes the NMAAHC as a monument, memorial and museum although the brief only called for a museum.[7] Adjaye reflects on the 400 year history of African American culture the NMAAHC traces 'the tragedy of 12 million people being displaced, a lot of them dying crossing the ocean… There is a kind of deep tragedy in it. The project is loaded with things unsaid as well as things said. The building had to be explicit in its narrative.'[8] The core of this narrative is aspiration.[9] Adjaye suggests: 'Thinking about time raises questions on our current prospects, as we review the future; architecture can increase connectivity and help us understand the circumstances of contemporary life.'[10]

Fig 4.1 The National Museum of African American History & Culture, architects: David Adjaye, Philip Freelon, Max Bond Jr. and SmithGroupJJR, completed in 2016

The popularity of the museum is reminiscent of the success of the Centre Pompidou by Richard Rogers and Renzo Piano following its opening in Paris, France, in 1977. The NMAAHC has had over one million visitors in its first four months since its opening on 24

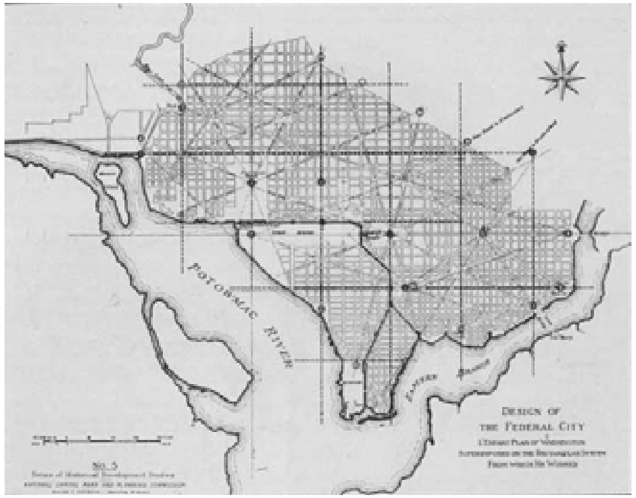


Fig 4.2 A Plan of Washington DC by William T. Partridge - *Design of the Federal City: Chart No. 5*, L'Enfant Plan of Washington superimposed on the Rectangular System from which he worked

September 2016 by President Barack Obama.[11]

Adjaye describes the site of the NMAAHC 'as a 'knuckle joint' that links the Washington Monument to the Mall.'[12] NMAAHC is a contemporary work of architecture in a neoclassical setting, which response to both its context and the narrative history celebrated in the building. Adjaye states 'my ideal public building has a square plan and is visible from all sides. The inherent symmetry of this form recommends it for public buildings, as it avoids the formal uncertainties that can attach themselves to other volumes.'[13] Suggesting that the NMAAHC has deep classical roots. However, he observes that 'examples of square – shaped public buildings in history are not as common as you would expect',[14] citing the anti-chamber at Luxor and the Great Mosque of Cordoba as key examples, although the latter is 'not quite square'.[15] He notes that Le Corbusier's square plan buildings include the Villa Savoye and the Assembly Building in Chandigarh and 'the square was important to Louis Khan, in designing the Jewish Community Center near Trento, for example.'[16] He considers:

> 'The National Mall, with the United States Capitol on the main axis and the White House on a cross-axis, represents one of the most coherently planned groups of building in the world and the design problem was less to do with acknowledging the monumental backdrop and more to do with adding a new voice – a sufficiently distinctive voice to encourage re-reading of the overview presented by the existing composition.'[17]

Adjaye observes: 'The building is classical in its inspiration, with a base and capital, but it's not a classical building. It's a very modern building in how contemporary thinking has been applied to material science and circulation.'[18] The base is formed from major below ground History Galleries, 'the crypt of the building', which are larger in plan than the visible bronze finished cast aluminium Corona.[19] Thus suppressing the apparent scale of this major museum. The base is in essence a four-storey podium sunken below the National Mall. The two primary elements of this composition are separated by a glazed ground floor, suggesting the beacon of the Corona floats above the landscape of the National Mall. The integrated assembly of the Corona is suspended from the roof trusses. Adjaye reflects 'I normally stop the outer façade above ground level, and at this point the architecture is about moving in and out of the building. The NMAAHC is an example of this arrangement.'[20] The visible Corona and glazed attic of the NMAAHC rises 31.5m above the National Mall. Adjaye intends the NMAAHC 'to complement its neighbors in scale and composition and to suggest, through its materiality and detailing, an alternative linage for the architecture of some of our neighbors.'[21]

The NMAAHC is in some respects reminiscent of the Villa Rotunda, near Vicenza, Italy, designed by the Renaissance architect Andrea Palladio (1570),[22] a clear antecedent to the White House. NMAAHC has a square plan that face the cardinal points of the compass yet on both buildings the four façades are essentially identical. Adjaye breaks this symmetry on the south façade by

Fig 4.3 The National Museum of African American History & Culture – is in essence a classical building

the deployment of a 55m spanning canopy to form an entrance porch. The cast aluminium cladding is treated as a universal system on all four façades. However, its primary performative role is to act as solar shading, helping the building to achieve LEED Gold.[23] This role is in essence not required on the North façade thus the formal or narrative intent of the cladding has determined the design thinking of the architect.

The Corona of the building comprising three tiers of cast aluminium panels, painted with bronze coloured PVDF. The form was inspired by a Yoruban caryatid topped by a Corona. The original column is displayed on the top floor and is on loan from the Haus der Kunst in Munich. The NMAAHC houses over 37,000 artefacts, other exhibits

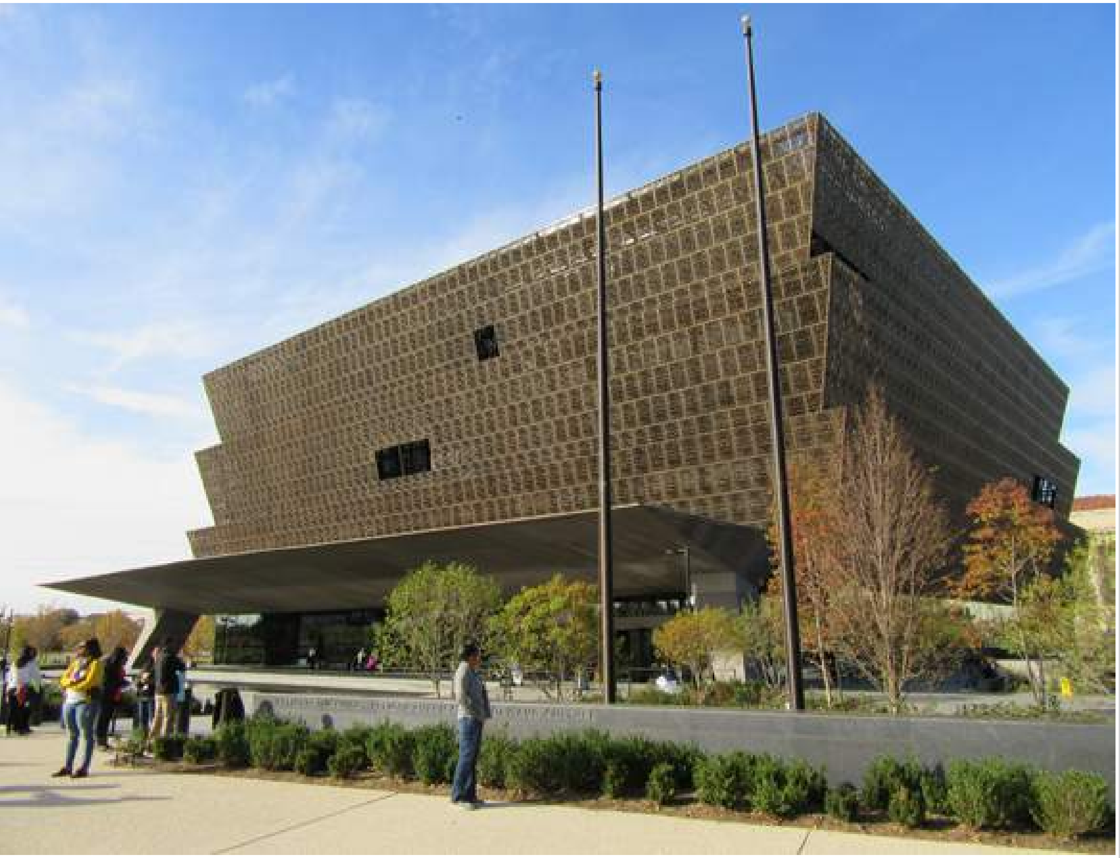


Fig 4.4 The generous canopy over the main entrance to The National Museum of African American History & Culture

include jazz scores by John Coltrane and Chuck Berry's 1973 Cadillac Eldorado. The inclined angle of the cast aluminium panels is a direct inversion of the 17º pyramidal cap of the Washington Monument. Architect Robert Mills won the competition for this monument to President George Washington in 1845, but it was not completed externally until 1884. When the almost 170m high stone obelisk was topped off by a cast aluminium cap that forms part of the lightening protection of the monument. This is one of the earliest uses of aluminium in civic architecture.

The cast aluminium panels of NMAAHC draw on the metalworking traditions of freed African-American slaves, especially in southern American cities such as Georgia, Charleston and New Orleans. In particular nineteenth century cast iron balconies in New Orleans, as illustrated in Figure 4.5, Adjaye observes 'people keep thinking that the slave trade was about cotton picking. It was also about bridge building, canals, house making. Labor in all its forms.'[24]

Fig 4.5 The tracery of a cast iron balcony in New Orleans, photographed between 1929 and 1926

The use of aluminium can be found in art from Africa – Figure 4.6 shows a wooden Dan mask from the Ivory Coast, which has a dark patina, yet has aluminium encircling the eyes. While Figure 4.7 shows is a Senoufo mask from Mali or Burkina Faso. This lost wax aluminium casting was probably produced during World War II. Both masks are in the Jean Plateau's Collection.[25]

There is also a broader tradition of the use of castings to form the facades of buildings in North America, from the cast iron façades in Chicago at the turn of the nineteenth century by Louis Sullivan,

Fig 4.6 A wooden Dan mask from the Ivory Coast, which has a dark patina, yet has aluminium encircling the eyes,

Fig 4.7 A cast aluminium Senoufo mask from Mali or Burkina Faso, circa 1944

for example the Carson, Pirie, Scott and Company Store, 1899 to the cast aluminium spandrel panels used by the architect William Lamb of Shreve, Lamb and Harmon to clad the Empire State Building in New York, 1931.

Cast aluminium was considered in competition with ultra high strength concrete (UHSC) and bronze.[26] Adjaye selected cast aluminium cladding for its durability responding to the

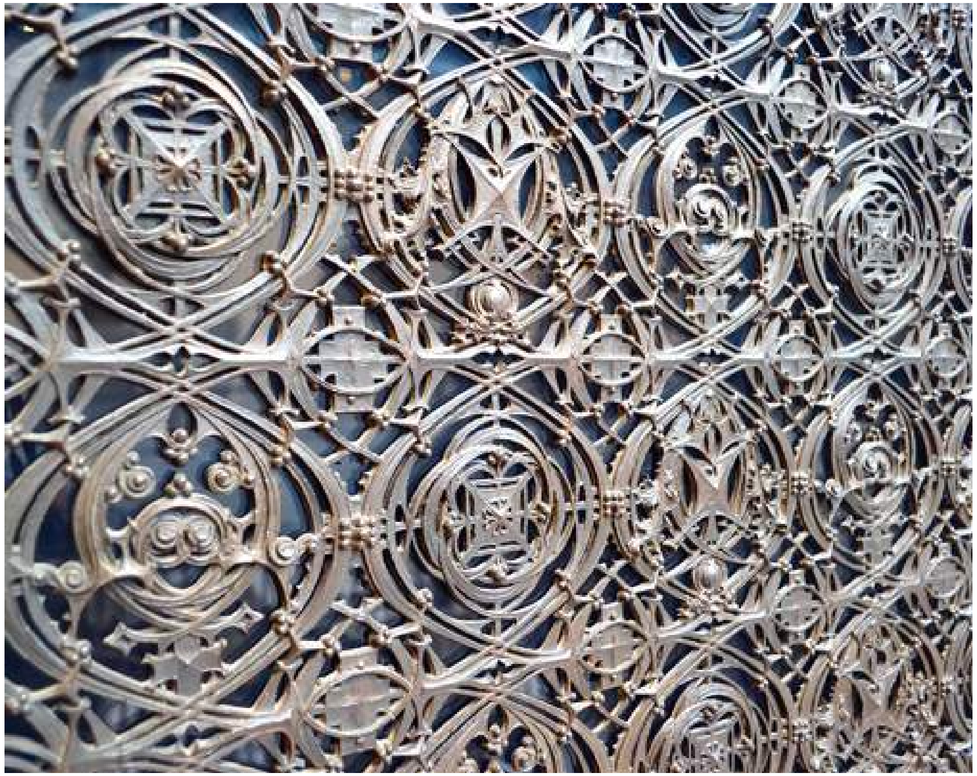


Fig 4.8 Cast iron tracery designed by Louis Sullivan in Chicago at the end of the nineteenth century

Smithsonian's brief for a 50-year guarantee. Six patterns are used in the cast aluminium panels that range in opacity from 65 to 90 per cent. Aluminium alloy used to cast the panels is equivalent to 3003-H14. The panels were cast using tooling made by Peerless Pattern Works, Inc. and cast in a foundry in Ohio by Morel Industries. The typical panel size is 1600mm high by 1048mm wide and 38mm deep (63" × 41.25" × 1.5"). Sample panels now form part of the NMAAHC's collection: a type A panel with 65 per cent opacity, a type F panel with 90 per cent opacity and a type E panel with 85

per cent opacity.[27]

The lightweight of the cast aluminium panels enables four workers bolt on a panel and if necessary disassemble it. In comparison with bronze, Adjaye observers: 'They are in the safety limits of allowing four strong men to be able to fix one — like glass, like the weight of a big, heavy double-glazed panel of glass. Whereas, bronze would be 10, 20 times as heavy.'[28] It was the foundry that made the design team aware of the sustainability of using recycled aluminium. Aluminium castings are typically produced from recycled material with a small proportion of primary material to balance the chemical composition of the specified alloy. *Aluminium Recyclability and Recycling,* the second book in the Towards Sustainable Cities series, records the extensive use of

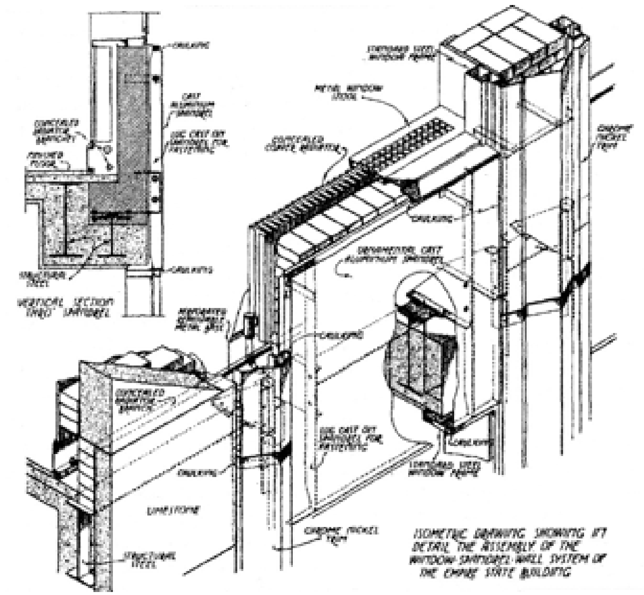


Fig 4.9 Isometric drawing showing the detail of the assembly of the window and cast aluminium spandrel panel of the Empire State Building, architect William F. Lamb of Shreve, Lamb & Harman

cast aluminium in contemporary architecture from the cladding of Ljubljana Television Centre, 1974, architect France Rihtar with Branko Kraševac to solar shading of Heelis, National Trust Headquarters Building, 2005, architect Fielden Clegg Bradley Studios. On both of these projects the cladding and solar shading is left as cast or foundry-finished.[29] At NMAAHC the cast aluminium panels are coated in a bronze coloured PVDF wet paint system by Dura Industries. Apparently PVDF was chosen in preference

Fig 4.10 The cast aluminium panels on the north façade of The National Museum of African American History & Culture

to bronze anodising for colour consistency between batches of panels.

Specialist subcontractors Enclos under took the detailed design and installation of the curtain walling, steel supporting trusses and cast aluminium solar shading. Enclos began designing only four months after the project had started on site, in June 2012, in close collaboration with the competition winning design team. The cast aluminium panels were prototyped by Enclos for structural performance before the main production run. They also produced complete mock up of the steel structure, unitised curtain walling and cast aluminium panels, which measured approximately 18.3m tall by 11.4m wide (60' by 37').[30] This integrated assembly of curtain walling, steel substructure and cast aluminium cladding has been design to provide blast resistance to a potential terrorist explosion.

This layered façade is characteristic of the work of Adjaye, which he first explored in houses built either side of the millennium 'the gap between the interior and exterior gives me – as the author – some relief, in reducing the obligation to impact the external world in an aggressive manner, which would be detrimental to building up successive layers of meaning.'[31] He also uses this gap to activate the section of a building and mediate between the space within and the city: 'Many of my buildings have an inner skin and an outer façade, and with this arrangement I can organize the façade with both the interior of the building and the scale of the city in mind.'[32]

Pattern making is important to Adjaye and is a key part of the narrative of this celebratory architecture of the NMAAHC: 'As the outer skin is … detached from the main structure, I can manipulate the pattern of the lattice in relation to the proportions of the building, the dimensions of the site, and the scale of neighboring buildings and spaces.' He continues, 'the patterns are intended to reveal the form and scale of each building as clearly as possible and, at the same time, to suggest that this form is not completely real. The patterns fail to explain many aspects of the building. As abstractions, they leave a great deal to the imagination'. [33]

Adjaye's architecture is often made from a combination of the formal and the informal. He observers the NMAAHC develops ideas used in the Idea Store, Whitechapel, London (2005) the

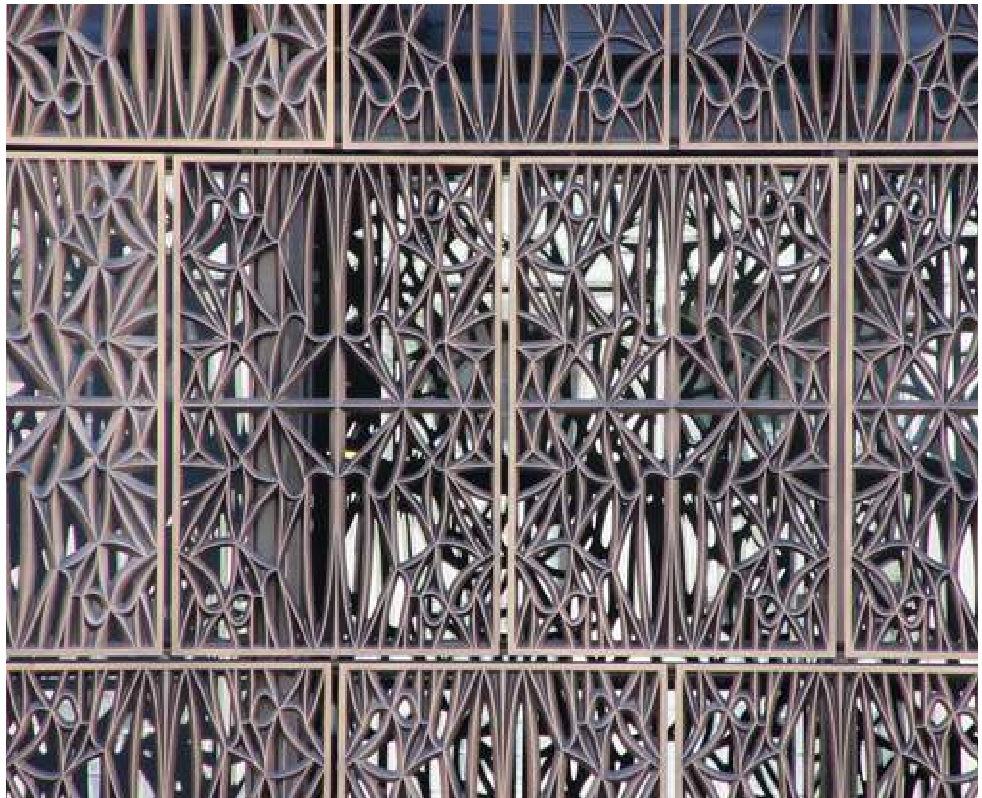


Fig 4.11 Six patterns of cast aluminium panels are used on all four elevations of The National Museum of African American History & Culture

Fig 4.12 The inclined angle of the cast aluminium panels of the NMAAHC is a direct inversion of the 17° pyramidal cast aluminium cap of the Washington Monument.

Fig 4.13 The author in the office of the Aluminum Association holding a full-sized replica of 17o pyramidal cast aluminium cap of the Washington Monument.

'promenade spaces that are essential to the overall function of the building and at the same time allow people to reflect on what is on offer and where they are in the city.'[34] Where the external form is in essence an inversion of the neoclassicism of its context the interior is less formal and non hierarchical. Within the NMAAHC, he believes 'there is no ambiguity about how the circulation works. From the monumental entrance hall, the main options are to go down to the History Galleries or up to the Corona, where there are further exhibits and views of the National Mall and the city. The choices are clear and presented without any suggestion of

Fig 4.14 The NMAAHC is a building that sings for all of us

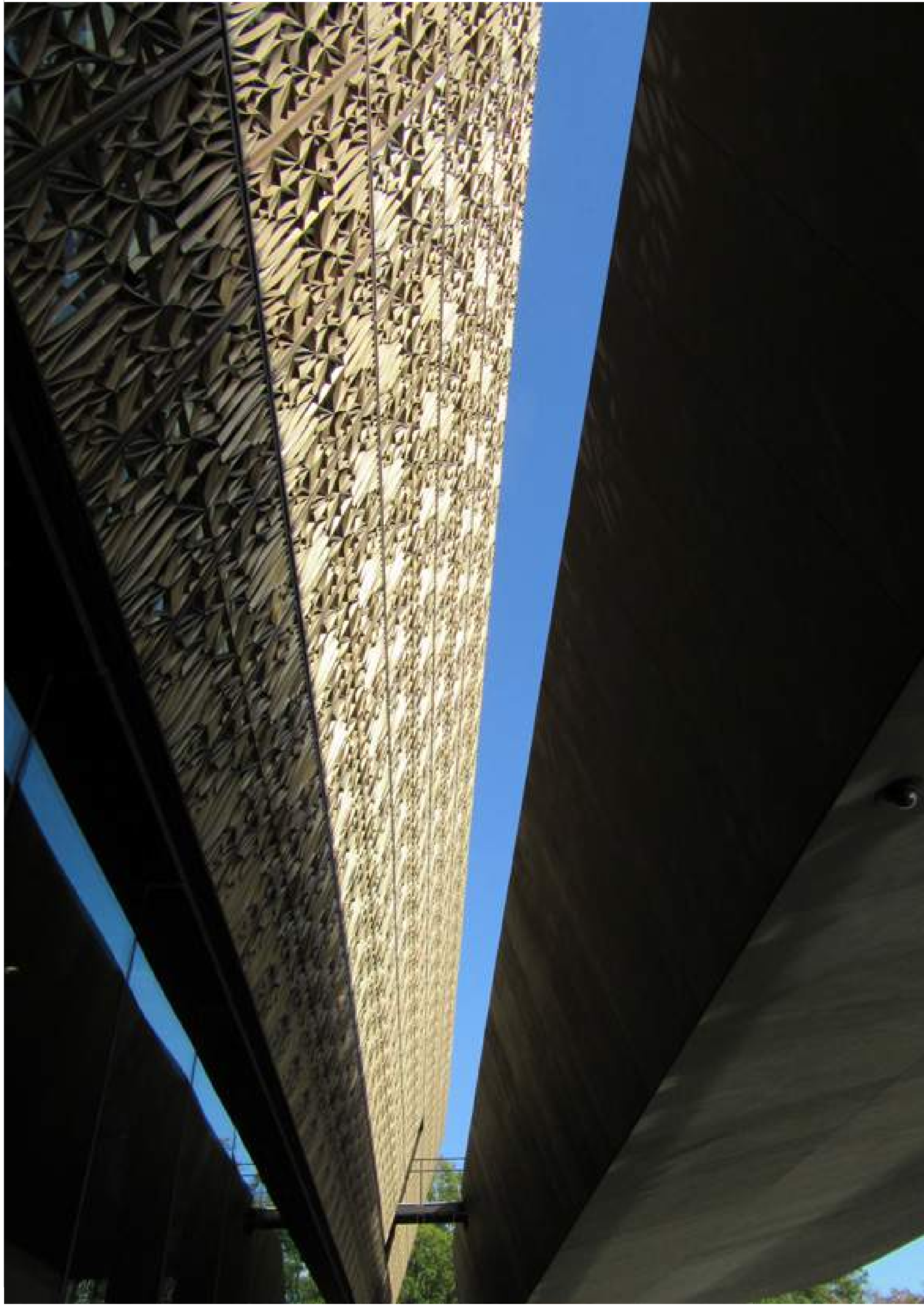
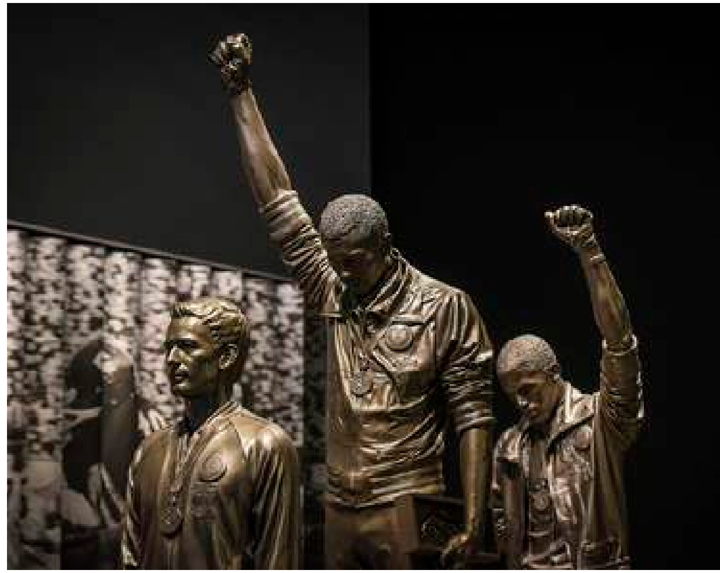


Fig 4.15 The dymanic shadows from the tracery of the cast aluminium cladding of the NMAAHC

Fig 4.16 Bronze sculpture by Richard Hunt of Tommie Smith and John Carlos raised black-gloved fists during the playing of the U.S. national anthem at 1968 Mexico Olympicsin, exhibited in the NMAAHC



hierarchy.'[35] The circulation spaces of the Corona are infused by the tracery of the cast aluminium panels. Adjaye intends that the visitors experience 'at every level is conditioned by having already seen the bronze finish facades of the Corona, and we have reinforced this connection in the materiality of the interior.'[36]

Although bronze coloured PVDF was selected to coat the cast aluminium panels for colour consistency, the design intension of this cladding would serve as a beacon of hope within the cityscape and political Washington D.C. and the United States of America. The design and depth of the cast panels help to generate a diversity of reflection and refractions from the façade. Adjaye observing visitors to the NMAAHC reports 'on a sunny day - people go, it's on fire!'[37] Materials, when used as components within architecture 'do not simply operate on their own account; the context in which you place them informs how they read.'[38]

It was on the steps of the Lincoln Memorial on the National Mall on 28 August 1963 that the civil rights activist Martin Luther King Jr. delivered his famous *I have a dream* speech, which poetically evoked the diverse landscape of America "let freedom rain – from the prodigious hill tops of New Hampshire, let freedom rain – from the mighty mountains of New York – let freedom rain" and infused this land with the hope of racial equality. [39] Lonnie G. Bunch III, founding director of the NMAAHC, described his hope for this work of civic architecture, "This building will sing for all of us."[40]

Notes

1 www.nps.gov/nr/travel/wash/lenfant.htm (accessed February 2017).
2 D.Adjaye, ed., P. Allison (2017) *David Adjaye Constructed Narratives,* Lars Müller, Zürich. Throughout the TSC book series, quotations originally written in American English have been quoted verbatim using spelling prevalent in American English.
3 Josephine Minutillo, (1 November 2016) *National Museum of African American History and Culture*, Architectural Record, (accessed February 2017, via *National Museum of African American History and Culture*, Architectural Record).
4 David Adjaye's knighthood was announced in HM Queen Elizabeth II's 2017 New Year's Honours List. He was knighted by Prince William at Buckingham Palace on 12 May 2017.
5 nmaahc.si.edu/explore/building (accessed February 2017).
6 *Only Artists:* Yinka Shonibare and David Adjaye, (26 April 2017) BBC Radio 4, transcribed by the author (accessed May 2017 via www.bbc.co.uk/programmes/b08n2y3b).
7 Ibid.
8 Ibid.
9 Ibid.
10 D.Adjaye, ed., P. Allison (2017) *David Adjaye Constructed Narratives,* Lars Müller, Zürich, p 233.
11 https://nmaahc.si.edu/about/news/national-museum-african-american-history-and-culture-reaches-milestone-1-million-visitors (Posted 20 February 2017 and access March 2017).
12 M Webb (February 2017) *Adjaye Associates' NMAAHC couldn't be just a building that was background to its content,* Architecture Review, (accessed via /www.architectural-review.com/buildings/adjaye-associates-nmaahc-couldnt-be-just-a-building-that-was-a-background-to-its-content/10016565.article February 2017)
13 D.Adjaye, ed., P. Allison (2017) *David Adjaye Constructed Narratives,* Lars Müller, Zürich, p 226.
14 Ibid, p. 227.
15 Ibid.
16 Ibid.
17 Ibid, p.233
18 M. Kimmelman, (21 September 2016) *David Adjaye on Designing a Museum That Speaks a Different Language*, New York Times, (https://nyti.ms/2d0iv5T accessed November 2016).
19 *Only Artists:* Yinka Shonibare and David Adjaye, (26 April 2017) BBC Radio 4, transcribed by the author (accessed May 2017 via www.bbc.co.uk/programmes/b08n2y3b).
20 D.Adjaye, ed. P. Allison (2017) *David Adjaye Constructed Narratives,* Lars Müller, Zürich, p 193.
21 D.Adjaye, ed. P. Allison (2017) *David Adjaye Constructed Narratives,* Lars Müller, Zürich, p 233.
22 J. S. Ackerman (1966) *Palladio*, Pelican Books, The Architects and Society Series, Harmondsworth.
23 The highest level of environmental accreditation in the LEED v4 (2014) rating system in Platinum. LEED and BREEAM are discussed in M. Stacey (2015) *Aluminium, Recyclability and Recycling: Towards Sustainable Cities*, Cwningen Press, Llundain.
24 M. Kimmelman, (21 September 2016) *David Adjaye on Designing a Museum That Speaks a Different Language*, New York Times, (https://nyti.ms/2d0iv5T accessed November 2016).
25 J. Plateau and I. Grinberg (2013) *Aluminium Passion: The Treasure Trove of the Collection of Jean Plateau – IHA*, Les Éditions Du Mécène, Paris pp. 178-179.

26 For more information on high performance concrete see M. Stacey (2011) *Concrete a studio design guide*, RIBA Publishing, pp. 23–28.
27 https://nmaahc.si.edu/explore/collection/search?edan_q=Corona&edan_local=1&op=Search (accessed February 2017).
28 M. Kimmelman, (21 September 2016) *David Adjaye on Designing a Museum That Speaks a Different Language*, New York Times, (https://nyti.ms/2d0iv5T accessed November 2016)
29 M. Stacey (2015) *Aluminium, Recyclability and Recycling: Towards Sustainable Cities*, Cwningen Press, Llundain, pp. 230–245.
30 A. Webanck, *The Design Assist Process: unique solutions through the hybridization of cultures and knowledge*, www.enclos.com/assets/docs/Insight03-Chapter05-TheDesign-AssistProcess.pdf (accessed April 2017).
31 D.Adjaye, ed., P. Allison (2017) *David Adjaye Constructed Narratives,* Lars Müller, Zürich, p 64.
32 Ibid, p.192.
33 Ibid, p 193.
34 Ibid, p. 191.
35 Ibid, p. 192.
36 Ibid, p. 101.
37 M. Kimmelman, (21 September 2016) *David Adjaye on Designing a Museum That Speaks a Different Language*, New York Times, (https://nyti.ms/2d0iv5T accessed November 2016).
38 Ibid, p. 91.
39 M. Luther King Jr. (28 August 1963) I had a dream, Lincoln Memorial Washington D.C. via YouTube www.youtube.com/watch?v=3vDWWy4CMhE
40 nmaahc.si.edu/explore/building (accessed February 2017).

Thoughts from Kew Gardens

This chapter is primarily formed from thoughts and ideas articulated during the Towards Sustainable Cities Symposium at Kew Gardens, on 31 October 2016. A full list of participants is included towards the conclusion of this book.

Fig 5.1 Interview with Julia Barfiled and Ian Crockford

Interview with Julia Barfield & Ian Crockford of Marks Barfield Architects

Michael Stacey – What is your response to visiting the Hive designed by Wolfgang Buttress, noting that Marks Barfield Architects has a project within Kew Gardens?

Julia Barfield – I think it is a triumph, it seems like it has come home. It's the perfect location for the Hive, being in this pavilion is completely immersive experientially and yet it communicates a very serious message, and it's very beautiful.

MS – What is your most inspirational aluminium based work of architecture or product?

Ian Crockford – North Greenwich Pavilions by Marks Barfield Architects, even though I worked for two years on the i360 in Brighton, which is a fantastic use of aluminium. At North Greenwich we used a standard product, but in a very different way.

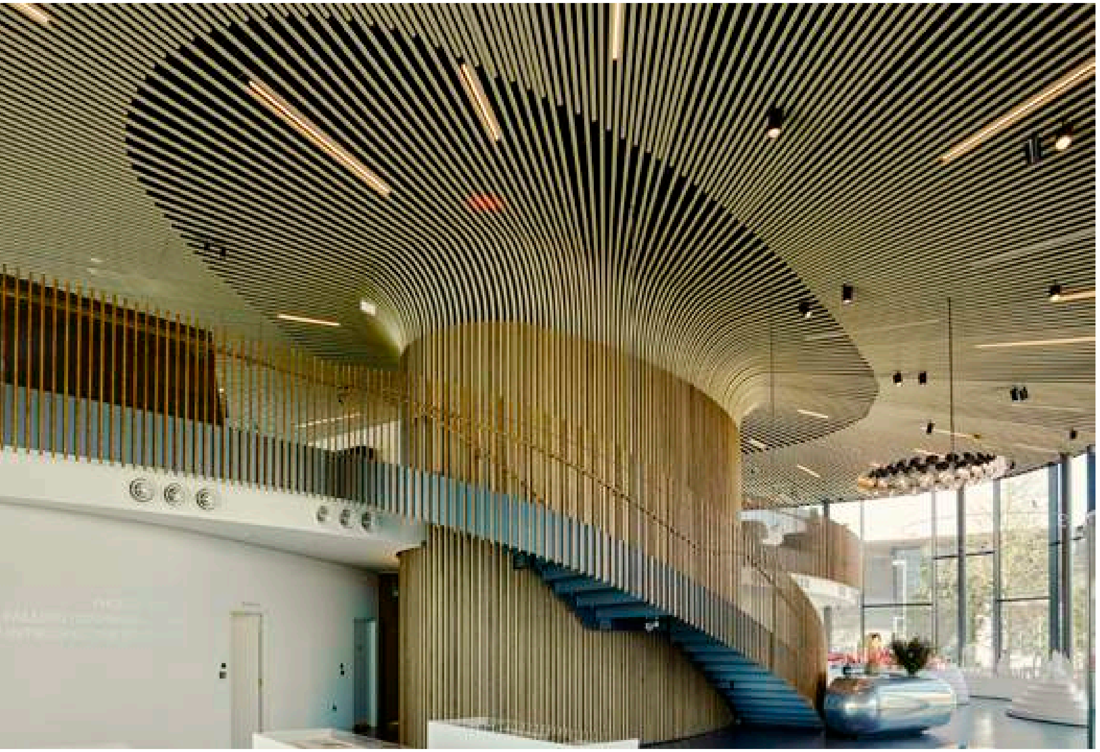
Fig 5.2 Greenwich Gateway Pavilions designed by Marks Barfield Architects, completed in 2016

MS – The North Greenwich Pavilions received a RIBA National Award in 2016 and are located just opposite the Millennium.

JB – Yes.

MS – Are you investigating the use of aluminium in a forthcoming project?

JB – We have a very exciting project in the Seychelles, on the island of Mahe, for a charity that has stewardship of this World Heritage Site of the Aldabra atoll, in the Indian Ocean. It can be described as the Galapagos of the Indian Ocean. The project is a small building but it needs to be highly sustainable. It's a visitor centre for this World Heritage Site that explains the ecology of this



atoll, as people cannot go there because it is protected. We are intrigued by the possible use of foamed aluminium as a cladding material, because it is strangely reminiscent of the geology of the atoll, of the volcanic rock of the island. Foamed aluminium also has practical qualities that would be beneficial in the tropical climate. A cladding material with some isolative properties but also would be durable in a very hot climate. But this just one example.

MS – One of the many current projects at Marks Barfield Architects.

MS – Thank you for taking part on today's symposium. Will anything you have learnt today influence your future practice?

JB – I think we have learnt a huge amount. The TSC research project is fantastic; many architects have quite limited understanding of aluminium and its durability and recyclability, all of the qualities we learnt about today. Many architects should consider the use aluminium. It's excellent to have the data about this construction material. I am not certain this exists for other materials, available today.

Fig 5.3 Bespoke tubular aluminium linings of Greenwich Gateway Pavilions designed by Marks Barfield Architects, made using a standard product

Fig 5.4 British Airways i360, Brighton, England, 2016, conceived and designed by Marks Barfield Architects

IC – I will take away the reappraisal of life cycle analysis and life cycle assesments (LCAs). 15 to 20 years ago, when the green movement started and showed footsteps in architecture, life cycle analysis was the be-all and end-all. It seems to have been forgotten, under BREEAM and LEED. I thought that was the most interesting take-away from today.

A detailed case study of the i360, Brighton, England, designed by Marks Barfield Architects and completed in 2016 is included in *Aluminium: Flexible and Light*.[1]

Interview with Jo Bacon, Partner and 'BIM Champion' at Allies & Morrison.

Michael Stacey – What is your response to visiting the Hive designed by Wolfgang Buttress?

Jo Bacon – I am really intrigued by the structure and the mill-finished aluminium and how its going to live, in this very organic atmosphere. It might encourage things to move in, it's a very occupiable space. I am also intrigued by the structure, as I don't think an architect would have designed it 'like that'. There is a freedom of being an artist where the edges are left unresolved. Had it been designed by architects, we would have frantically been worrying about the resolution of the geometry and what would happen at the edges.

MS – Is Allies & Morrison investigating the use of aluminium in a forthcoming project?

JB – I do not know of a project that we are doing that will not be using aluminium, somewhere in the assembly of the building fabric.

MS – Your designing a tower in the city of London.

JB – I am working on 100 Bishopsgate, which is a 40-storey retail and office building. This is being clad with aluminium curtain walling, supplied by a Chinese specialist subcontractor. The smallest project in the office is a pavilion for Darwin College, Cambridge, which has aluminium doors and windows.

MS – Is this project designed to Passivhaus standards.

JB – No, we used Passivhaus standards on another project in Cambridge, Ash Court at Girton College, completed in 2013. This has triple glazed aluminium windows to achieve the required thermal performance.

MS – As Allies & Morrison's 'BIM Champion', do you think there will be a strong take-up of life cycle thinking linked to BIM by construction professionals and suppliers?

JB – I think that for the institutional clients and the clients who continue to own and manage their buildings, it's that input that they will expect to get from Allies & Morrison, as lead designers. We are definitely interested in life cycle thinking and we think it is part of our responsibility. The challenge is making the whole design team contribute, to make the calculations truly effective. Without everyone's involvement, one is going banging on a door and not having much success. Life cycle assessments (LCA) are dependent on the quality of data collected. If everyone contributes that will be very beneficial. For clients who intend to own and manage their properties for the next 100 years plus, LCA is a very useful tool.

Fig 5.5 The Hive designed by Wolfgang Buttress in the Royal Botanical Gardens, Kew, London, 2016

Fig 5.6 Interview with Jo Bacon

MS – Thank you for taking part in today's symposium here at Kew Gardens. What will you take away that will influence your future practice?

JB – It felt today that many architects were feeding back to the aluminium industry on how we see the material, how we are considering using this light metal. It would be interesting to organise a symposium the other way around, by inviting aluminium suppliers, fabricators, leading industrialists, such as Hilde Merete Aasheim of Norsk Hydro to our office to talk from their perspective. For the architects to learn about smelting, fabrication and other processes, and the environmental concerns from that end of the spectrum, which we do not get to hear often enough.

MS – Perhaps we need to reverse the dialogue? Today was quite unusual for leading architects, engineers and artists to be in discussion with CEOs and Directors of major aluminium companies.

It's rare to get all of those people in one room at one time.

JB – I think not enough architects understand the process of making aluminium, the people in my office would be fascinated to see how you get to a Schüco aluminium section, that we are often looking at, where does that come from, what power mix is used, how much is recyclable and how much is recycled.

Fig 5.7 Ash Court, Girton College, Cambridge, England, architect Allies & Morrison, 2013

Fig 5.8 Ash Court, thermally broken triple glazed aluminium window, louvers and precast concrete

Fig 5.9 **Ash Court, Girton College, Cambridge, England, architect Allies & Morrison, 2013**

Interview with Tim Lucas, Partner in Price & Myers

Michael Stacey – Tim what is your response to visiting the Hive designed by Wolfgang Buttress?

Tim Lucas – I am very lucky to live in Kew and I know Wolfgang. It is really wonderful project. I think Wolfgang's achievement in getting it to Milan and now Kew is great, especially as a Kew resident. But as a structure and piece of engineering its very enjoyable thing to have in the area, it's an admirable piece of work. A lot of care, consideration and thought has gone into how to make something look very random but has an underlying rationality, which is nice to see when you look at it and try to understand it.

MS – I should have thought of this. You are both an engineer who has collaborated with Wolfgang Buttress and a local resident, who lives in a famous house, which you commissioned.

TL – Yes, but the house is not made from aluminium.

MS – What is your most inspirational project using aluminium either your own, or product by someone else, or project you have collaborated on?

TL – In terms of a project using aluminium we are very pleased with the sculpture we built in London's Southbank Tower with an artist, Tobias Putrih, and curated by Future City, it was a great experience. With the guys in my team pushing the aluminium design code to the limit and thus achieving something stunningly transparent. In terms of other projects in today's symposium, I think the potential of using aluminium extrusions, possibly adaptable extrusions, if such technology exists, would be very interesting. What I learnt from today is that there are multiple ways of joining and fabricating aluminium that I have not thought of before. Different kinds of welding and adhesive techniques, for instance, that we could use as structural engineers in buildings, bridges, and large scale sculptures.

MS – Do you think that aluminium is well enough understood by structural engineers?

TL – It does not have the body of design resources that other materials have. I think that is something engineers would welcome. When we work with aluminium we have to go back to first principles and to the code [Euro Code-9] and lower E-value [**Young's modulus of Elasticity**], means that buckling is an important consideration for frame structures. More resources would be helpful, such as software to establish the capacity of members or how we look at a bespoke section and get all the properties, without spending hours

Fig 5.10 Vertical Shell, artist Tobas Putrih, engineer Price & Myers

going through books and codes. Worked examples would also be a good idea. Other material design guides have a body of worked examples and this would give young engineers the confidence is using and persevering with how to use aluminium structurally.

MS – In the symposium you mentioned the need for research into intumescent coatings for aluminium section to provide fire protection?

TL – Or how you dissipate heat from an aluminium section? Or how you insulate it? To be able to use aluminium in wider range of applications would be very interesting. There is a suite of materials that are always considered in construction, but to solve the dissipation of heat in a fire be that through an intumescent coating, or through composite action with concrete or through water-cooling. There are lots of techniques that could be looked at and combined with bespoke aluminium extrusions that could lead to interesting solutions for fire resistant structures.

Vertical Shell, designed by artist Tobias Putrih with engineers Price & Myers, is discussed in detail in TSC Book Four *Aluminium Flexible and Light*.[2]

Fig 5.11 **Michael Ramwell and Jenny Grewcock managing the interviews at Kew Gardens**

Interview with Jim Eyre, Founding Partner of WilkinsonEyre

Michael Stacey – Jim, what is your response to visiting the Hive designed by Wolfgang Buttress, noting that WilkinsonEyre designed the Alpine House here at Kew Gardens?

Jim Eyre – well it's lovely to see such an open and dynamic and loose structure that is quite plant like, in a funny kind of way. It is also reminiscent of a Hive, with many hexagonal patterns coming together. It is an extraordinary experience, when architecture really works well it is almost a spiritual experience being in that space. I certainly felt that today.

Fig 5.12 Interview with Jim Eyre

MS – Do you think that aluminium can be described as sympathetic and powerful? Furthermore, Is this an appropriate description of the anodised aluminium windows of the New Bodleian Library [now renamed the Weston Library]?

JE – Aluminium is an exceptional material because of its shear versatility. Used carefully, it can achieve a feeling of lightness, which is a form of power in itself. Not used carefully, it can be very heavy and appear heavier than steel! Using it for windows on the Bodleian Library you need to know about it to know its aluminium, because otherwise they just look like rather slender windows.

MS – What is your most inspirational aluminium based work of architecture or product, from your own work or by other architects or designers?

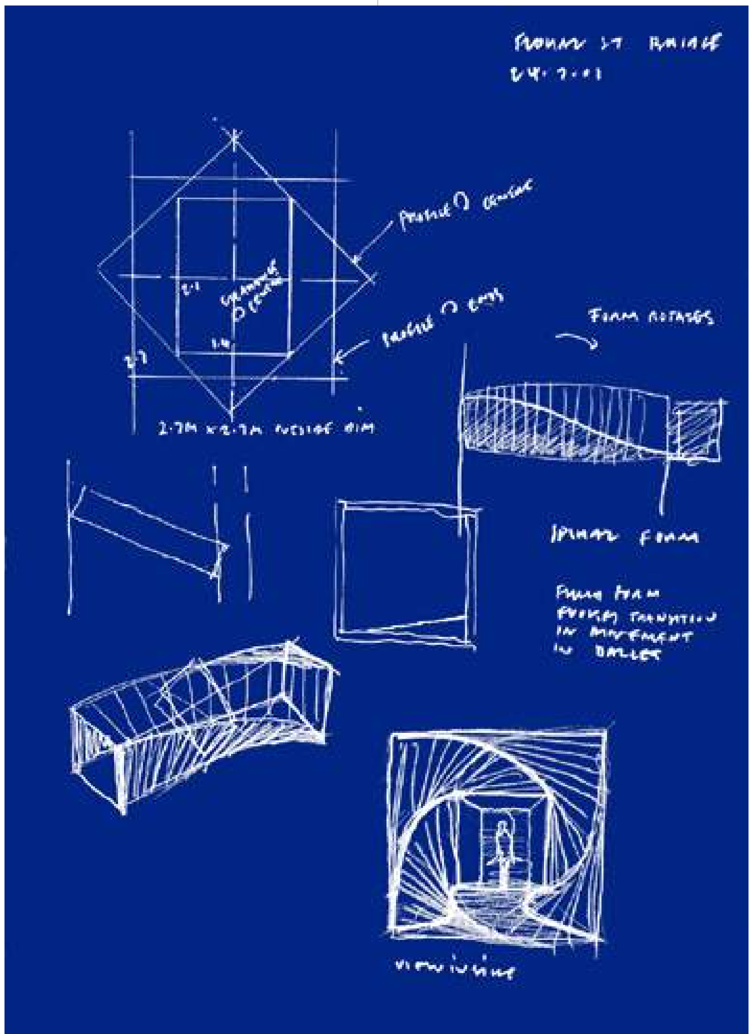


Fig 5.13 Jim Eyre's initial sketches of the Bridge of Aspiration

JE – I think because of the shear level of inspiration, partly from the geometry and the idea of expressing the geometry, it has to be the Bridge of Aspiration on Floral Street, Covent Garden, London. Many of WilkinsonEyre's projects use aluminium, but that is the one for me where the expression of material is almost at its optimum.

It works because of contrast of with another material, the contrast of a natural material, wood, with aluminium. It is truly exceptional, with the two materials working together to speak of the geometry, the geometrical expression. It is very special.

Fig 5.14 The Bridge of Aspiration being craned into position above Floral Street, Covent Garden, London

MS – Thank you for taking part in today's symposium. Will it influence your future practice at WilkinsonEyre?

JE – I learnt quite a lot at the symposium today. There were particular things I needed to know more about, life span of finishes on aluminium, for instance, and the sourcing of aluminium. How the aluminium itself is produced, we need the equivalent of 'FSC' for wood, but for aluminium. The publications you are producing are potentially extremely useful for architects in the office. One needs to understand the various ways to produce aluminium into diverse form, what the production methods are. This kind of information will enable you to understand what you can do with it. Knowledge is powerful.

Fig 5.15 The Bridge of Aspiration, Covent Garden, London: architect WilkinsonEyre, 2003

Interview with Mo Panam, Joint Managing Director of Barley Chalu

Michael Stacey – Mo, what is your response to visiting the Hive here at Kew Gardens designed by Wolfgang Buttress?

Mo Panam – My initial response was that it is delightful and peaceful. The use aluminium combined with nature is inspiring.

MS – What is the role of quality control in delivery durable finishes on aluminium, which have long service life, if periodically washed?

MP – Quality control is part of the process that we should look into to achieve longevity and therefore the sustainability of the building. I think it is necessary to examine the complete supply chain from the raw materials, the processing of the aluminium and the finishing of the aluminium. Testing aluminium finishes is very important and understanding that testing is also very important to the potential contribution of the finishes to the longevity of a building.

Fig 5.16 Interview with Mo Panam

MS – Do you think architects and specifiers should approach finishes much earlier in their design process and really find about the options. Do they leave it too late, or perhaps almost too late?

MP – Absolutely. This symposium is a great opportunity to bridge the gap. We do not have all the answers, but we can answer their questions on performance for example, too many specifiers

Fig 5.17 Barley Chalu's computer controlled anodising line, installed in 2016

do leave it too late. We can make their lives much easier by just speaking to the specifier from the outset, while they are designing. I would welcome architects contacting early and asking about the potential finishes on aluminium.

MS – Noting that Barley Chalu has installed a new anodising line in your works in Norfolk, England, in 2016. Why do you think anodising is popular with architects and specifiers? Is it's durability or that it retains and reveals the aluminium below the hard coating?

MP – I think it is a bit of both. Anodising is the earliest finish that architects are aware of. Your studies reveal anodising from the 1920s and 1930s, whereas robust polyester power coating, becomes available much later in the twentieth century. The beauty of aluminium is not hidden by hard and clear film anodising, known as silver or natural anodising and even when using colour anodising finish you still have the metal reflected through the very durable finish. We at Barley Chalu in Wymondham, Norkork, are very proud of what we are doing and we are pioneers, we have 'new tricks up our sleeves' to help architects. For example we have investing in a new state of the art computer controlled anodisng line.

MS – Thank you for taking part in today's symposium, from the things you have learnt today, what will influence your future practice of your company?

MP – One of the most important things I have learnt today is that engineers and architects would like more assurance on the durability of finishes on aluminium, which we can supply. They need data that they can rely upon and put into the 'armoury' of their specifications. Based on trusted test data from professional bodies such as Qualicoat, CAB and ALFED, as I am involved in all three.

Interview with Billie Faircloth, Partner at KieranTimberlake

Michael Stacey – Billie, what is your response to visiting the Hive here at Kew Gardens designed by Wolfgang Buttress?

Billie Faircloth – The Hive? To look at it in photographs did not do it justice. This we know. However, the photographs reveal the part to whole relationship, which is very hard to see as you walk around it. So I spent quite a bit of time examining the interrelationship between the form described by the parts, this becomes clear. But you can't really understand the Hive without the sound. It's the part – to whole – to sound – the blanket – the pillow.

MS – An immersive experience? However you brought your own blanket and pillow, in your imagination.

BF – In essence the Hive is an immersive experience, in which one becomes an active participant.

MS – Do you think there will be a strong take-up of life cycle thinking by construction professionals and suppliers?

BF – I think there needs to be a strong take up of life cycle thinking,

Fig 5.18 Interview with Billie Faircloth

across the value chain. We are in a moment when this practice is emerging, especially for designers. It is being taken up beyond individual designers who have been interested in life cycle thinking for sometime. It's being taken up by LEED and BREEAM, with the support of those two organisations and two schemes, we are now going to see translation across the value chain, from clients beginning to wrestle with what Life Cycle Assessments (LCAs) are, to architects now having to begin to understand this modelling practice. It's not, do I wish, or do I hope, but vital for the design team to take this up, if we want to understand environmental impacts. We have to continuously pursue ways of measuring or modelling them, otherwise we will never know.

MS – Based on Jo Bacon's response in the symposium, she saw that as a challenge to the design team and may be a risk or new pressure on architects' fees. Are these manageable issues?

BF – It's absolutely manageable. Practically, we have applied LCA to a number of architectural projects. This enables KieranTimberlake to engage design decision-making with multiple sources of information. This is another type of information, which can be directly connected to the materials that we specify, that we should become familiar with.

MS – Can you comment on the process of researching and writing TSC Book Three *Aluminium and Life Cycle Thinking*, as part of the Towards Sustainable Cities series?[3]

BF – KieranTimberlake approached this research enthusiastically, to broker a conversation across the primary and secondary manufactures, connecting knowledge they have about the processes to designers. Our engagement with life cycle thinking and specifically life cycle assessment, as a modelling practice in TCS Book Three, was intentionally constructed to point out some of the tensions that exist in this process. In the modelling process itself and the understanding and messaging of the outcomes of LCA modelling. We aligned TCS Book Three strategically with the facts gleaned in TCS Books One and Two. What we were seeking to do was to show how those facts have agency and allow us to make fundamental questions about aluminium. Especially when it comes to questions of recyclability and our perceptions of durability. At the outset our primary perception was that aluminium is energy intensive and how can we get around that? What we found, collectively, was a great disparity in the literature and the way life cycle assessments have been constructed in the past. There is great variable in the capacity for testing our perception by using life cycle assessments, especially when we connected to crucial facts from exemplar case studies and contemporary case studies.

MS – Thank you for taking part on today's symposium. Are there things you might take away to influence the future practice of KieranTimberlake? Or issues that in your opinion need further research?

BF – Today we discussed the way in which as architects we have to wrestle with complex assemblies. This is a continuous discussion over many years, may be even decades. When it comes to paradigms of recycling, paradigms of manufacturing, designing with materials and placing them where they make the most sense. There definitely is an area of research that needs to be expanded upon. Certainly people are working on this, research that begins to match life cycle impacts with the durability of materials. We have made a start but there is more research to be done in this field.

Our practice at KieranTimberlake is trans-disciplinary; we have purposely set up processes in which we interrogate questions about architecture and the built environment. Our practice is constantly evolving. As we find new questions to ask, new methods to deploy and new ways to make real connections between design, form making, performance making and knowledge.

TCS Book Three *Aluminium and Life Cycle Thinking* begins to evidence the way in which in depth research, the framing of important questions, can then be taken up and looked at and then become actionable. For us we are interested in actionable information and I think this is actionable.

Fig 5.19 Cellophane House at MOMA, New York, USA, 2008

Interview with Alex de la Chevrotière, CEO of the MAADI Group

Michael Stacey – Alex, I understand that you have come all the way from Canada to attend this symposium. In Canada with MAADI Group you design and fabricate all-aluminium bridges?

Alex de la Chevrotière – Yes. But I actually do more that just bridges, designing and fabricating all types of civil and marine structures. All the structures are engineered by the MAADI Group and fabricated in our workshop. We are known for all-aluminium pedestrian bridges, because we have made so many.

Fig 5.20 A prototype deployable military bridge, designed and fabricated in aluminium alloys by MAADI Group for the Canadian Army, 2017

MS – What is your response to visiting the Hive designed by Wolfgang Buttress, here at Kew Gardens?

AdlC – Beautiful, for me it is a mixture of hard architecture, science and nature, and engineering, focused on the plight of the honeybee. It's a beautiful project and I was delighted to meet the artist.

MS – What is your most inspirational aluminium based work of architecture or product?

AdlC – It's a good question. I have experienced many good aluminium projects in my career, for example Mazzolani Superdome structures. But as an engineer the aircraft structures are a source of inspiration, they have proven that aluminium is a structural material.

MS – Do you think the construction industry has a lot to learn form aerospace and automotive industries, which we can transfer into architecture and infrastructure?

AdlC – Yes, unfortunately we work in a conservative world. I think the aircraft industry and the military bring us many developments using aluminium, which we all can take profit from. As you know we work with the Canadian Army designing deployable bridges. For the military the first price is not the key question, it is durability and sustainability. The total cost of ownership is important to them. Thus aluminium is the metal often selected in this context.

MS – This year you have designed and tested a rapidly deployable bridge for the Canadian Army.

AdlC – We have been mandated by the Canadian Army to provide a rapidly deployable bridge that can be used in earthquakes including the one that recently hit Haiti and hurricane zones in the Gulf of Mexico. The bridge can be delopyed in 80 minutes, without the use of a crane. It is assembled by hand by eight troopers from prefabricated aluminium elements. The bridge is not welded it is assembled using cast aluminium nodes and bolts that go through the neutral access of each members. Thus only a few components are needed to make a bridge.

MS – Is there renaissance in the specification of all-aluminium pedestrian bridges and why is this the case?

AdlC – MAADI Group has been involved in the design and assembly of bridges for many years now. Earlier in my career I had been working for a large dock manufacturer, fabricating large structural aluminium gangways. Proving aluminium to be an outstanding material, even in a salty humid marine environment. We should be prompting the use of aluminium, it is a material for the future. It lasts forever.

MS – Thank you for taking part on today's symposium. Are there things you heard or learnt that may to influence the future practice of your company?

Fig 5.21 46,3m welded aluminium alloy bridge, designed and fabricated by MAADI, being craned into postion, 2014, published with permission from the oil extraction comapny

AdlC – I have met very nice people. I would congratulate you on your book *Aluminium, Flexible and Light*. This was a missing 'piece' in my field and now we have a book that shows creativity in the use of aluminium, not just by engineers but also architects and designers. This series of books will open the minds and creativity of many people. I have met many very interesting people and for me this is the start of a long collaboration.

MS – Merci beaucoup, Alex.

AdlC – Thank you, Michael.

This chapter reflecting on the symposium at the Royal Botanical Garden, Kew concludes with a discussion on the processes of undertaking the research that underpins the Towards Sustainable Cities programme and what has been learnt from this research on a collective and individual basis. All the participants studied architecture (MArch, RIBA Part Two) at The University of Nottingham as part of the Making Architecture Research Studio, led by the author and then subsequently worked on the research at Michael Stacey Architects, over a period of three years. The research workers are:

- Laura Gaskell;
- Jenny Grewcock;
- Ben Stanforth;
- Michael Ramwell;
- Philip Noone.

Michael Stacey – Outside the context of MArch architecture studio at The University of Nottingham, this is the first time we have all been together, the complete team who worked on the Towards Sustainable Cities (TSC) research programme. What I would like you to do is to discuss aspects of the research that you undertook, starting with you Laura and TSC Book One *Aluminium and Durability*.[4]

Laura Gaskell – *Aluminium and Durability* being the first book was literally an adventure into aluminium. As many architects stated today aluminium is in nearly every building made today, thus finding what we dubbed the pioneers of aluminium was a challenge. Michael you have this amazing way of making research fun. I think it was fun to come to work every day and work on the TSC research. With so many interesting projects, it is difficult to decide which projects inspires me the most or was the most interesting to research. We all went to Rome to photograph San Gioacchino church (1897). While we were photographing the church, the priest came in and allowed us to continue. He knew he had a great work of architecture in his custodianship.

MS – It's great to hear that we can make research fun, that's great news. Jenny would you like to talk about the next book.

Jenny Grewcock – TSC Book Two *Aluminium: Recyclability and Recycling* was interesting for many reasons, including the study of the in-use life span of aluminium used in architecture.[5] I particularly enjoyed researching deployable structures, for which aluminium is very appropriate as it is lightweight, durable and yet infinitely recyclable. I was struck by the flexibility of the many ways in which aluminium can be used in architecture. Part of our research

Fig 5.22 The complete Michael Stacey Architects team, part of the TSC research group, at the Hive, Kew Gardens: Ben Stanforth, Jenny Grewcock, Laura Gaskell, Professor Michael Stacey, Michael Ramwell and Philip Noone, who took the photograph

was short-life structures, including exhibition pavilions from Jean Prouvé's Aluminium Centenary Pavilion, Paris, 1954, Thomas Heatherwick's Shanghai Expo UK Pavilion, 2010 all the way to the Hive by Wolfgang Buttress, 2015, which aptly was a temporary structure and now seems to be permanently residing in Kew Gardens.

MS – Ben, you led the research into the onsite testing of finishes on aluminium that were older than their original guarantees and at least 25 years old. Can you describe your involvement? Which is recorded in TSC Book One.

Ben Stanforth – The TSC Symposium at Kew Gardens has provided me with the perfect opportunity to reflect upon my experience of working with Michael Stacey Architects on the first publication in the Towards Sustainable Cities series, *Aluminium and Durability*.[6] The research I undertook alongside Michael gave me the opportunity to investigate one specific material, aluminium, which on a personal level enabled me to focus on a scale of architectural design that I had not previously done, whilst studying at the University of Nottingham.

Fig 5.23 The Michael Stacey Architects team, part of the TSC research group, at Kew Gardens including Philip Noone

MS – Ben, there you are specifically referring to my next book *Aluminium: a studio design guide* for RIBA Publishing, which will be accessible enough for first year students but deep enough to be used in practice, for both architecture and engineering, to inform design decisions and specification. This book will draw together the best case studies and key finding from the TSC research programme. From my perspective it is excellent that all four of you have agreed to be on the advisory editorial board for this series of Studio Design Guides, of which aluminium will be the second book in that series.[7]

BS – The research process quickly developed my knowledge giving me a wide-ranging introduction into the types of use, historic architectural exemplars, production types, life cycle analysis and qualities of aluminium. As a former student I can clearly see the benefit of the consolidation of this information into one easy to access educational resource. This should prove useful as an educative tool at University for students across a wide range of degree courses from architecture to material sciences and in architectural practice for professionals.

Chapter Six in Aluminium and Durability, *Non-Destructive Testing* represents a key part of the research.[8] I found it very informative to go to site with Geoffrey Addicott of independent testing organisation, Exova, to undertake non-destructive testing on the finishes to aluminium building components of three exemplar buildings:

- The New Bodleian Library, Sir Giles Gilbert Scott (1940) - refurbished by WilkinsonEyre (2015);
- Herman Miller Factory, Grimshaw Architects (1983);
- 1 Finsbury Place, Arup Associates (1985).

The testing of colour, gloss and film thickness was undertaken as part of the research. In summary this testing showed that for their age (each building is over 25 years old) the aluminium cladding was in good condition – minimal filiform corrosion was located on the Herman Miller Factory panels, but only on the very sheltered east façade and some apparent corrosion on the anodising of One Finsbury Place, was noted but only on the cut ends of sections at relatively geometrically complex junctions. This testing showed that aluminium often lasts longer than the guarantees offered by suppliers and manufactures. This set of tests provided quantifiable data on the durability of both anodised and polyester powder coated aluminium, which served as the scientific core of the research.

Today, reflecting on undertaking the non-destructive testing as a practicing Architect, I believe it is our responsibility to truly understand the materials that we are specifying for our buildings. It is important to learn from previous projects and to glean lessons learnt which can be done so by utilising RIBA Stage Seven 'in-use' to improve our design decisions.

Finally, the TSC Symposium was a great opportunity for many different members of the design and construction industry including; designers, architects, engineers, manufactures, scientists and many others to continue this dialogue to ensure more thoughtful and responsible design is undertaken with the aim of improving our built environment.

MS – Michael Ramwell, would you like to start the discussion on TSC Book Four, which got a little bit larger than we were all expecting!

Michael Ramwell – *Aluminium Flexible and Light,* within the TSC series, shows the strength of aluminium. I have learnt a lot about the versatility about the different uses of aluminium, combined with the heritage of aluminium.[9] How it has been successfully used for many many years and it should no longer be regarded as a new material. For example, San Gioacchinoi church in Rome that Laura referred to, has an aluminium clad dome and is the oldest existing example of aluminium used externally and will be 120 years old next year. Although *Aluminium Flexible and Light* highlights how adaptable aluminium is and that new alloys and new uses are being discovered. Earlier today discussing Building Information Modelling (BIM) and Tally with Billie Faircloth of KieranTimberlake, our research partners, one of the key sections in Chapter Five was a life cycle assessment (LCA) study of formwork for the in-situ casting of concrete, comparing the use of timber formwork with a reusable aluminium formwork, produced by PERI. This LCA study was carried out in-house by Michael Stacey Architects using Revit® BIM software and Tally® LCA software. This study highlighted the in design benefits of an architect using a BIM software with an LCA plug-in, which Tally® is.

We compared the range of environmental impacts generated by the use of timber formwork versus aluminium formwork, which is reusable some 250 times. This later figure is backed up by earlier research included in the book. This study highlights the versatility, strength and lightness of aluminium in-use and how that can play a role in reducing the environmental impacts of constructing buildings. The complete TSC book series highlights the reduction of environmental impacts through the specification of aluminium in architecture and the built environment, for example as structure, cladding and glazing sections.

I have learnt from this research the adaptability of aluminium to enable specifers and designers to create a more sustainable built environment.

MS – Philip would you like to continue the story of TSC Book 4?

Philip Noone – Yes. I agree that it is the flexibility of aluminium that makes it interesting and useful. The book explores the use of aluminium in architecture, products, sculptures and art pieces, such as the Hive. Another interesting application was the Vertical Shell designed by the artist Tobias Putrih and engineered by Price & Myers. The constraint of the existing concrete slab and floor meant that the choice of aluminium as a lightweight material allowed it to be cantilevered, apparently effortlessly.

MS – It's 14 meters tall?

Philip Noone – Yes, yet the aluminium fins are only 3.2mm thick, the lightness of the structure enabled it to be cantilevered from the existing slab and the Vertical Shell appears to just emerge from the stone floor.

Another interesting case study, which I visited with Michael Stacey, was the de Havilland Comet Flight Test Hangar in Hatfield. This is an excellent example of aluminium being used as the primary structure, roof decking and cladding. The use of aluminium as primary structure is covered well in the bridges section. The aluminium structure of the Comet Flight Test Hangar spans over 60m, it was completed in 1953 and yet over 60 years later it was still in good condition.

For me working on the TSC research was a great learning experience, as Tim Lucas stated in the symposium if you don't learn about materials such as aluminium, at university or before, then you do not understand the full potential it has.

MS – Today, I really enjoyed hearing people like Jim Eyre talk about their projects, because we have studied them and written about them, they have allowed us to know which aluminium alloys they have used. Yet there are still little details that the architect or lead partner brings alive that perhaps we cannot capture in a book.

Laura Gaskell – If only we could have spoken to Jean Prouvé!

MS – I have talked with his son Claude Prouvé, who is an architect, unlike his father who was a metalworker. One of the strangest things that happened to me is, Laura, you carefully translated the Prouvé Centenary Pavilion case study (1954) from French to English, which celebrated 100 years since the chemical production of aluminium in France. This was the big break through in the mid nineteenth century, yet aluminium was very expensive so it was used to make beautiful sculptures and the court of Napoleon III served dinner to special guests aluminium plates. At the time aluminium was perceived to be more valuable than gold. So, Laura you carefully translated a monograph on this pavilion, and we wrote it up in TSC Book Two and then the first time I presented this was in Montréal, Canada, where it was simultaneously translated back into French! To me this seemed a rich irony. However, the French Canadians are very proud of the simultaneous discovery in 1886 of the current smelting technique for aluminium, the Hall-Héroult process, discovered by a French scientist Paul Héroult and an American scientist Charles Martin Hall. Interestingly Hall's elder sister Julia Brainerd Hall was a key participant in this discovery. She is in danger of becoming a forgotten woman scientist, when she is a key aluminium pioneer.

We saw Billie Faircloth earlier and I think it was good that we gave her and her colleagues Stephanie Carlisle and Efrie Frielander space in TSC Book Three to write up the research into Life Cycle Thinking.[10] Although as discussed by Billie earlier, this was based on work that Ben Stanforth had undertaken on maintenance cycles, which is recorded in TSC Book One. Ben was also the lead researcher on the onsite testing, which coincided with Prototyping Architecture. It might surprise people, today, that we have not just done aluminium research for three years and nothing else.

Fig 5.24 Laura Gaskell's study model of the aluminium curtain walling, shutters and structure of the London Makers Foundation, her award winning thesis project in Studio Mars at The University of Nottingham, 2013.

Notes

1 M. Stacey (2016) *Aluminium, Flexible and Light: Towards Sustainable Cities*, Cwningen Press, Llundain, pp. 568 – 582.
2 Ibid, pp. 322–328.
3 E. Friedlander, S. Carlisle, B. Faircloth (2014) *Life Cycle Thinking: Towards Sustainable Cities*, Cwningen Press, Llundain
4 M. Stacey (2014) *Aluminium and Durability: Towards Sustainable Cities*, Cwningen Press, Llundain, second edition 2105
5 M. Stacey (2015) *Aluminium: Recyclability and Recycling: Towards Sustainable Cities*, Cwningen Press, Llundain
6 Ben Stanforth had to leave early to return to his current architectural practice Feilden Clegg Bradley Studios and therefore provided his reflections in text form to the author.
7 M. Stacey (2011) Concrete: a studio design guide, RIBA Publishing, London.
8 M. Stacey (2014) *Aluminium and Durability: Towards Sustainable Cities*, Cwningen Press, Llundain, second edition 2105, pp 227–255.
9 M. Stacey (2016) *Aluminium Flexible and Light: Towards Sustainable Cities*, Cwningen Press, Llundain
10 E. Friedlander, S. Carlisle, B. Faircloth (2014) *Life Cycle Thinking: Towards Sustainable Cities*, Cwningen Press, Llundain

Fig 5.25 The two videos of the interviews conducted at Kew Gardens as part of the Towards Sustainable Cities Symposium can be viewed on Youtube via:
- https://youtu.be/qqye49QvZQA
- https://youtu.be/xM0YEX4NYXc

Fig 5.26 Wolfgang Buttress and Jim Eyre discussing art and architecture in the Hive, 2016

maximising the potential of aluminium

Maximising the Potential of Aluminium

The overriding theme that emerged from the TSC Symposium at the Royal Botanical Gardens Kew:

> Application of aluminium in architecture and the built environment should not seek wholesale replacement or displacement of other constructional materials. Instead, the aim should be to maximise the potential use of aluminium via an active and collaborative dialogue between end users, notably architects, engineers and product designers, with the aluminium industry; from smelters, extruders, finishers and fabricators.

We live in a multi-material world, where specifiers of architecture and infrastructure have an extremely wide range of materials to draw upon. A key task of this research is to help these specifiers make informed and appropriate choices.

This chapter highlights the on going potential and uptake of aluminium in architecture and infrastructure. The chapter sets out case studies, which range from the relocation or refurbishment of architecture from the 1930s and 1960s, to contemporary applications in Netherlands, Germany, Spain, Brazil, China, Scotland, and England. This selection is an update on the many successful applications of aluminium in architecture and infrastructure, discussed in TSC Books One to Four.

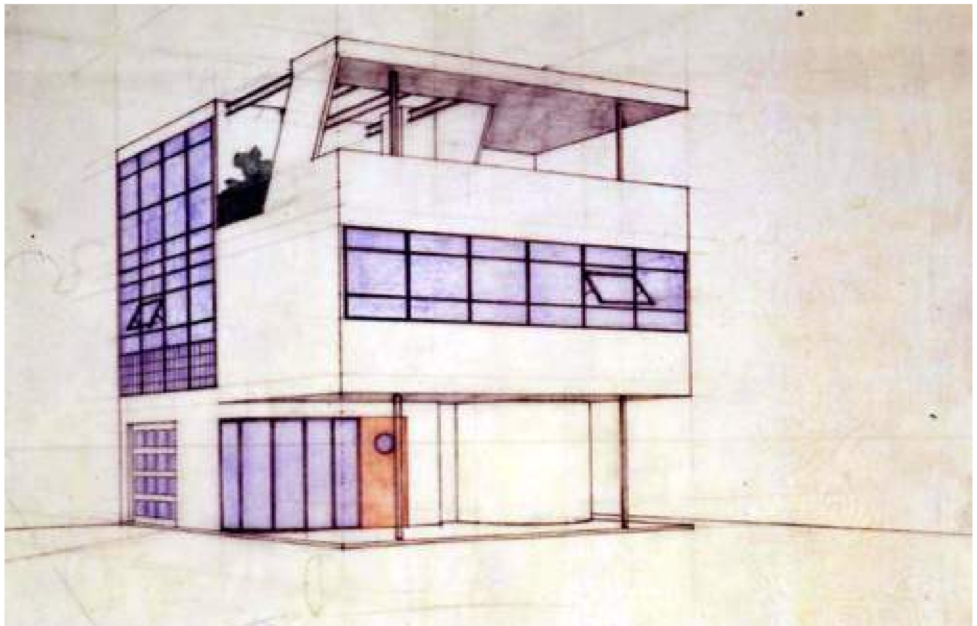


Fig 6.1 Albert Frey's sketch of the Aluminaire House

Aluminaire House, Long Island, New York, USA: Architect A. Lawrence Kocher and Albert Frey, 1931

This prototypical compact modern home was designed for the 50^{th} Architectural League of New York Exhibition, which was staged with the Allied Arts and Industries Association Exhibition. This exhibition opened in April 1931 and the Aluminaire House was displayed inside Manhattan's Grand Central Palace.[1] It was designed by A. Lawrence Kocher, managing editor of Architectural Record magazine, and Albert Frey, a Swiss born architect who had emigrated to the USA in 1930, having worked for Le Corbusier in Paris, for two years. Colin Davis observes that Frey had, whilst working in Le Corbusier's Atelier, 'produced a full set of working drawings for the Villa Savoye' – a seminal Modern Movement house.[2]

Clearly the design of the Aluminaire House was influenced by Le Corbusier's *Five Points of the New Architecture* and his Domino House, with its use of ribbon windows, piloti (columns) on the ground floor and a roof terrace. However, its construction from aluminium and light steel reveals the influence of American manufacturing companies.[3] The Aluminaire is a one bedroom home dedicated to healthy living, with ample daylight and a third-floor roof terrace, which promotes access to fresh air. The first floor bedroom with its en-suite bathroom includes an exercise zone divided off by a folding screen. The bedroom is supported by two circular aluminium columns. The primary structure of the house is aluminium with lightweight steel floor decks. 'According to Frey, the name 'Aluminiare' suggests modernity: "It had aluminium in it, you know, and it was very airy. And luminaire also means light", records Neil Jackson.[4] Its interesting to note that the design sketches for the house are dated October and November 1930, Frey was only 28 years old at this time.

Although compact, the Aluminaire House is spacious with a double height living room and library on the first floor through which, a straight stair leads to the roof terrace. The west elevation of the library is a wall of glass. The Aluminaire house is clad in micro-profiled aluminium sheet, with the profile running vertically. It is face fixed with aluminium screws, with aluminium washers to internal timber battens on steel angles substructure, see Figure 6.6. The aluminium for the house was supplied by Alcoa, and Truscon manufactured the steel floor decks.[5] The semi-circular bay on the ground floor is not part of the entrance sequence – it houses a boiler.

On completion of the exhibition, the house was bought by architect

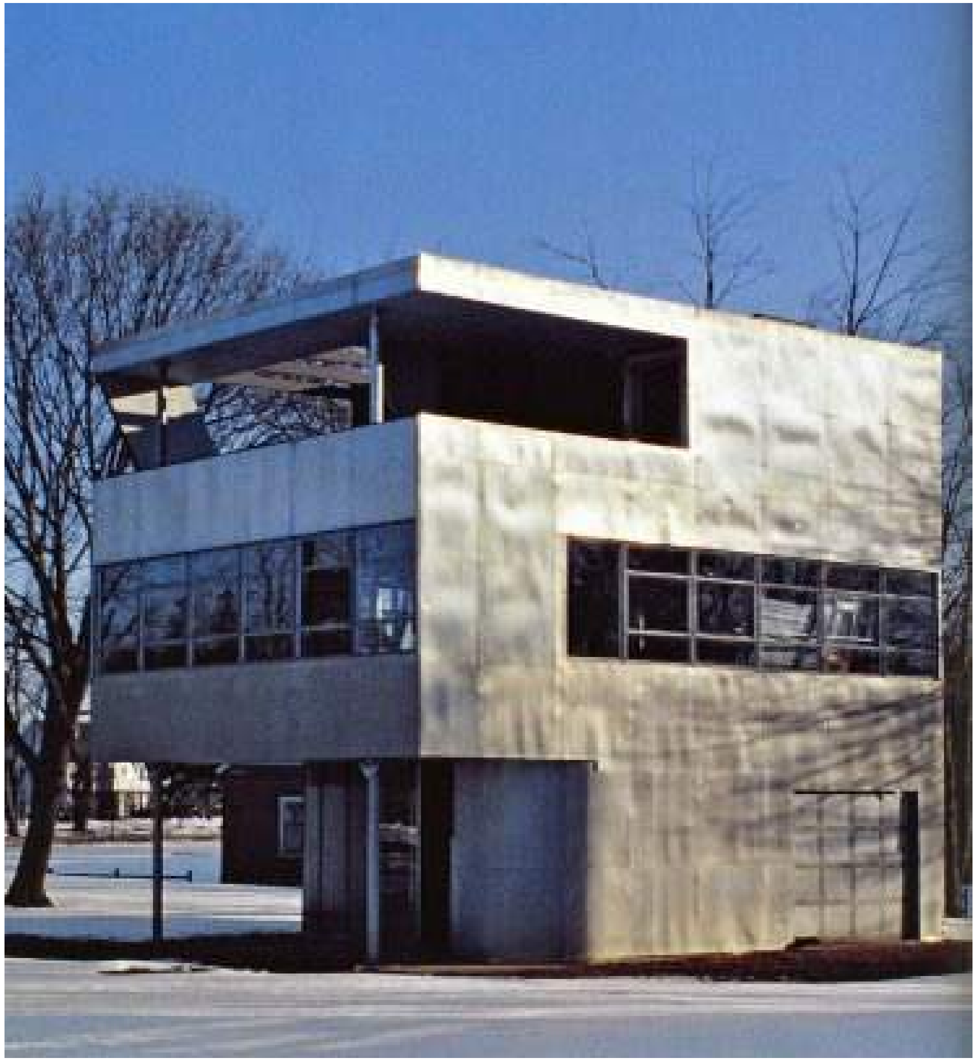


Fig 6.2 The aluminium clad Aluminaire House, architect A. Lawrence Kocher and Albert Frey, 1931

Wallace Harrison for $1000 who reassembled it on Long Island Estate.[6] Thus, the Aluminaire House is not only an early example of the use of aluminium in North America, it is an early demonstration of the benefits of design for disassembly (DfD), although this term will not be coined for about another 70 years, as discussed in TSC Book Two *Aluminium: Recyclability and Recycling.*[7]

In 1932, Henry Russell Hitcock and Philip Johnson included the house in The International Style exhibition at New York's Museum

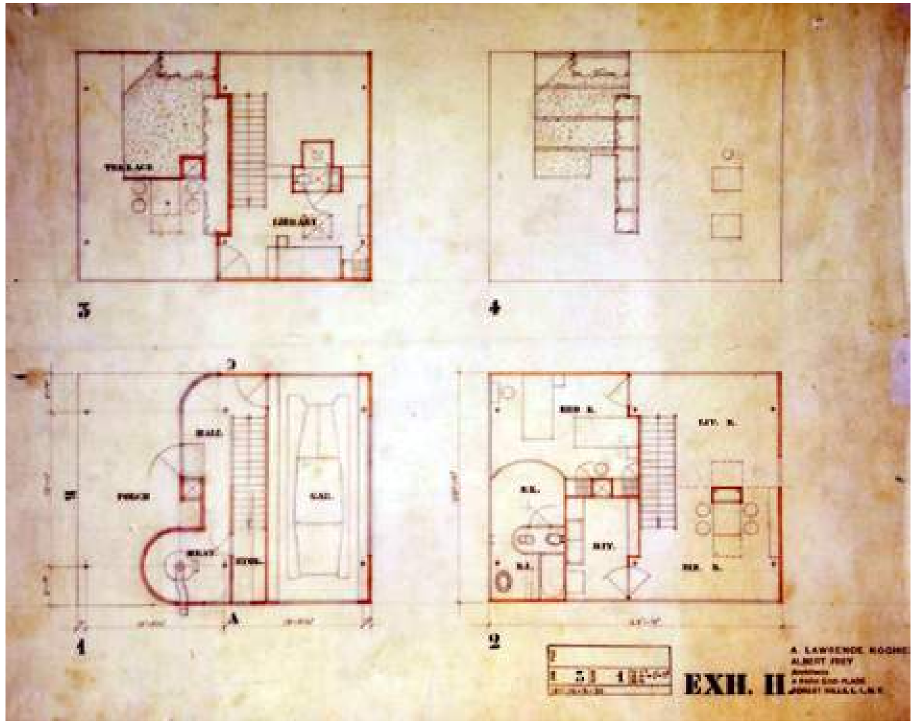


Fig 6.3 Lawrence Kocher and Albert Frey's plans of the Aluminaire House,1931

of Modern Art, a turning point for the development of Modern Architecture in North America.[8] In 1940, Wallace Harrison relocated the house to serve as a guest house on another part of his estate. It was the listed on the National Register of Historic Places (the USA's heritage listing process) in December 1985 yet was threatened with demolition by new owners who were dividing up the estate. Jon Michael Schwarting, chairman of the New York Institute of Technology's School of Architecture, saved the house and it was disassembled and related to Central Islip campus, where it was reassembled by architecture students over a three year period. When Colin Davies wrote *Key Houses of the Twentieth Century* (2005) the Aluminaire House was on the Central Islip campus of New York Institute of Technology.[9]

In 2006, NYIT ended most of its academic programmes on Central Islip campus and put the land up for sale. In 2010, the Aluminaire House Foundation was formed, and the dissembled house was placed in storage on Long Island. In February 2017, the components were relocated to California to be reassembled on a site opposite Palm Springs Art Museum. The Aluminaire is due to be fully

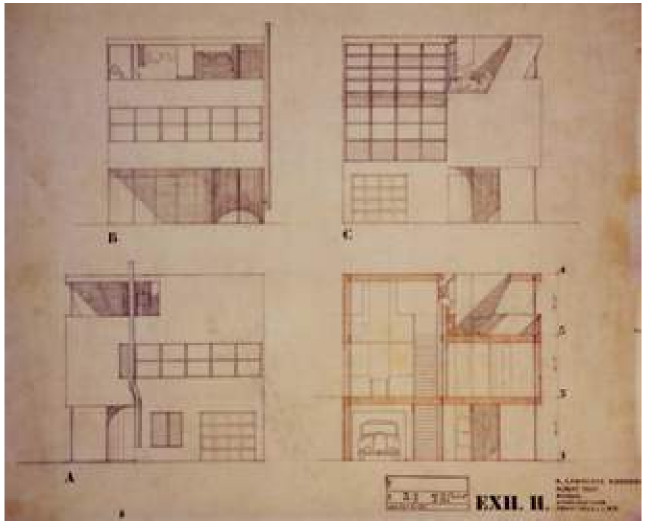
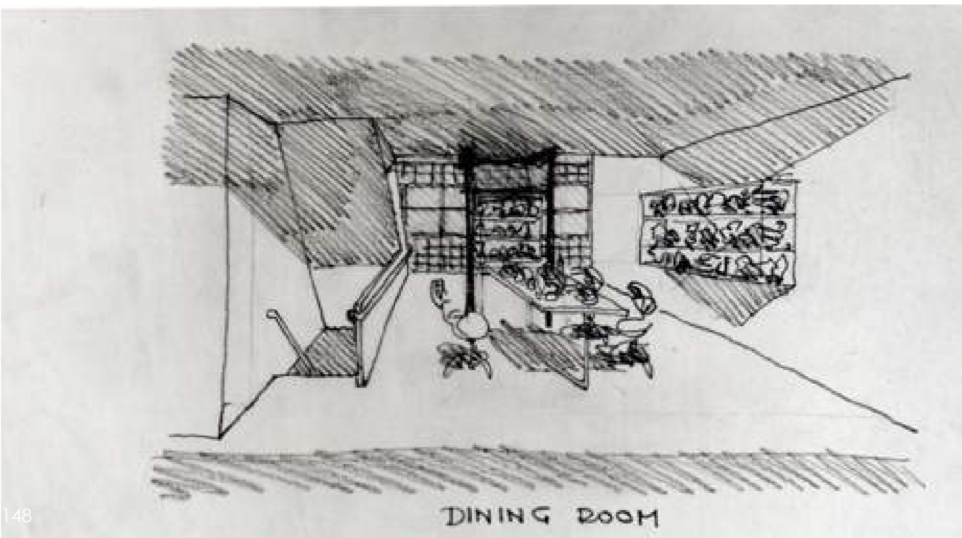


Fig 6.4 Lawrence Kocher and Albert Frey's elevations of the Aluminaire House,1931

reassembled during 2020, once the nes site a Plam Springs park is ready. In its 86-year life, so far, the Aluminaire has been assembled and reassembled in five distinct locations. It was intended to be a prototype of affordable housing in 1930s America. However, The New York Times on 8 March 1987 suggested: "The Aluminaire House was designed with a different goal – to prove the applicability of modernist theory to middle-class housing, to hold out the promise of a light, airy, open new world."[10] It is a delightful modest yet spacious home that has proven to be an exemplar of design for disassembly and reassembly.

Fig 6.5 Albert Frey's 1930 sketch of the dining room of the Aluminaire House



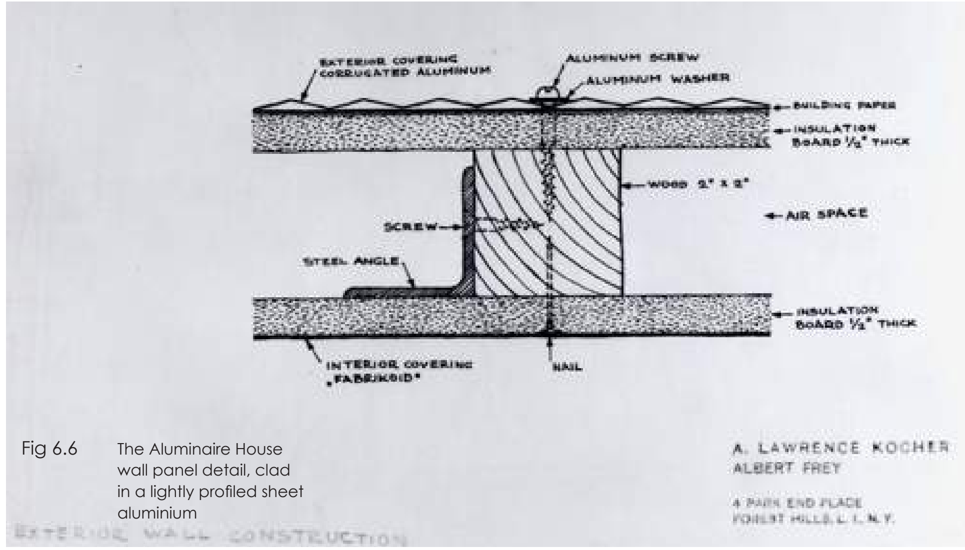


Fig 6.6 The Aluminaire House wall panel detail, clad in a lightly profiled sheet aluminium

Fig 6.7 The Aluminaire House

Harrods Escalator Hall Five, London, England: Interior Architect J. L. Harvey, 1939, Refurbishment Architect Make, 2016

Charles Henry Harrod, who opened his first store on Borough High Street in 1824, founded Harrods in 1849. In 1851, he moved the store to a small premises within the demise of the current site in Knightsbridge. His aim of this move was to exploit the footfall of the Great Exhibition, held in Joseph Paxton's Crystal Palace in nearby Hyde Park. Harrods installed its first moving staircase or escalator in 1898. The faience clad building completed in 1905, which is largely as we know it today. It was designed by architect Charles William Stephens.

Fig 6.8 Harrods Escalator Hall Five, 1938

Harrods has five escalator halls. Escalator Hall Five, which is sited at Door Five, was originally fitted out in 1938 to Art Deco designs by architect J. L. Harvey and formed Harrods largest entrance. The interior made extensive use of anodised aluminium. Anodising was only introduced in the 1920s. In a brochure supplied by the Harrods Archive, The British Aluminium Company who supplied the aluminium recorded the wide ranging use of aluminium in the fit out of Escalator Hall Five: 'Extrusions, sheet, castings, forging and even machined components are used with skill and ingenuity to facilitate construction and at the same time build up a harmonious whole.'[11] All the aluminium components were anodised by Alumilite & Alzak Aluminium Protection Co. Ltd, (Flight International Magazine 26 January 1967 records that this company was still trading in Merton Abbey, London SW19.) Using both silver anodising and dyed anodising in a 'delicate shade of coral' pink.[12]

Key details in the escalator hall used 'Imprest' Aluminium, a trade mark of British Aluminium, described as a 'new development whereby aluminium or aluminium alloy sheets and panels can be given a wide variety of decorative finishes' and although permanent, it was typically finished with lacquer or anodising.[13]

The escalator hall serves five floors, originally had street-facing windows, which were encased in aluminium, with banks of cast aluminium grills between them. The bespoke hanging pendant

Fig 6.9 Harrods Escalator Hall Five, 2016

lights of the escalator hall also used aluminium castings, sheet and extrusions, with a machined aluminium tassel. These were fabricated by J Starkie Gardner Ltd who also made casings and balustrading for the original escalators. The escalator engineers were J & E Hall Ltd. British Aluminium produced the aluminium from alumina. [14] Figure 6.18 shows how extensive this company's operations were in the United Kingdom and Northern Ireland, Eire and Norway in 1938. 45 years later, during 1983, British Aluminium merged with Alcan Aluminium (UK) to form British Alcan.[15]

Architect Make have refurbished Escalator Hall Five at a cost of £20million, work started on site late January 2016 and was complete by the end of October of the same year – ready for the Christmas rush. Make have successfully undertaken earlier projects for Harrods including SuperBrands and Escalator Hall Three. Restoring and remaking Escalator Hall Five resulted from close collaboration with Harrods, including its archivists, followed with careful consultation with Kensington & Chelsea Council and conservation architect Hilary Bell.[16] Make has specified 16 new escalators, removing escalators from 1983 and 1996. The architect has opened-up the five floors of Escalator Hall Five with Viennese biscuit-shaped cut outs on the second and fourth floor toped by new dome roof light crowning floor Five. The first raise of escalators from the ground floor return at a mezzanine level without touching

Fig 6.10 Harrods Escalator Hall Five, 1938

the wall and are cantilevered from the ground and first floors. This generates a greater sense of space, permits long views and recognises that this is a twenty-first century reinvention of Escalator Hall Five.

Make's design included stripping out post-1930s work. It is believed that the windows to the street were boarded up during World War II and this remained in place until the 2016 refurbishment. The architect has carefully organised the retention and restoration of key Art Deco aluminium components including the hanging lamps and the cast aluminium grills. These are now finished in

Fig 6.11 Detail of the curved and profiled aluminium escalator cladding

Fig 6.12 Harrods Escalator Hall Five, photographed in 2016

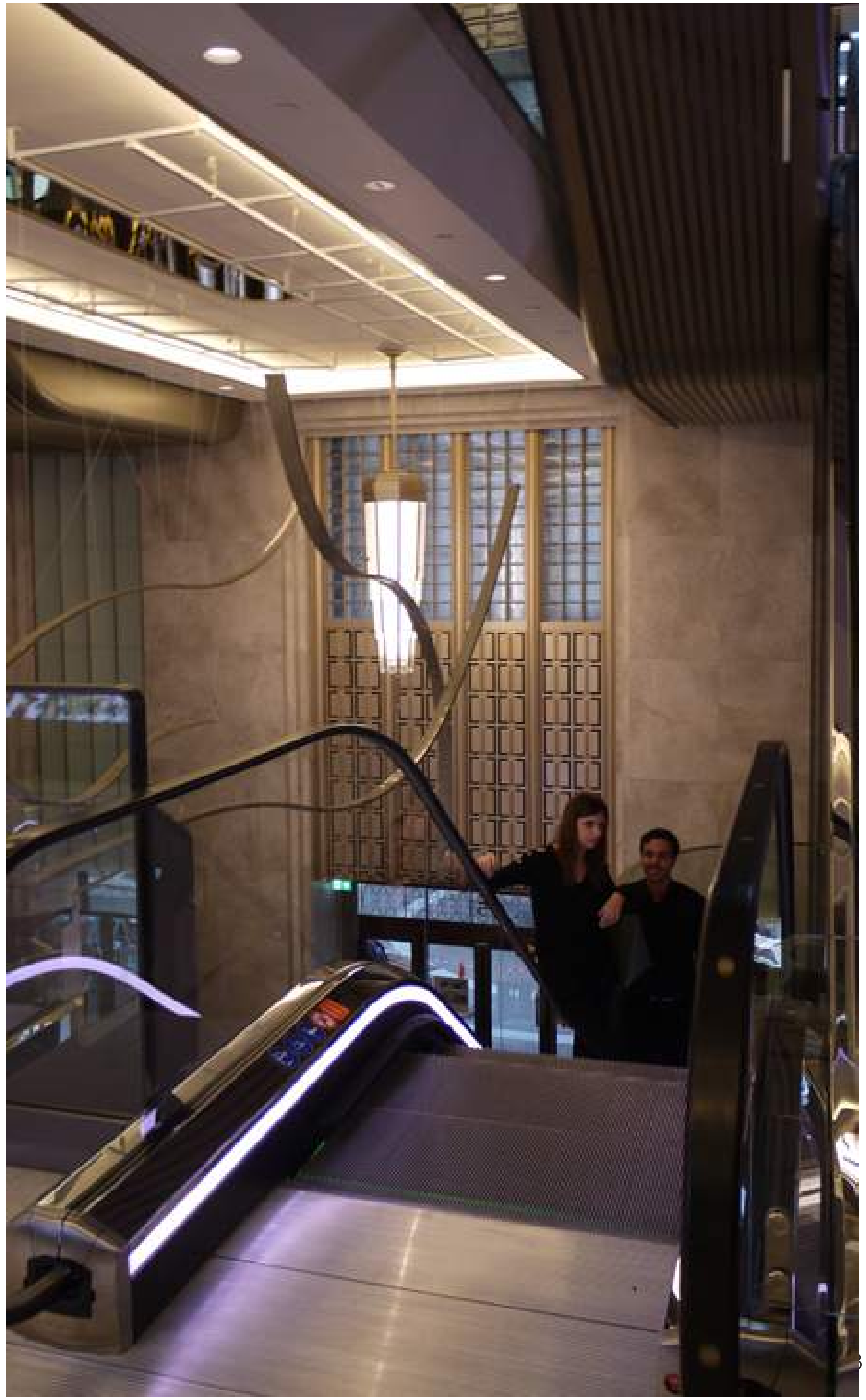


Fig 6.13 Harrods Escalator Hall Five, 2016

Nickel Bronze 'Liquid Metal' – a wet applied paint system that is about twice as thick as polyester powder coating. So sadly, the coral pink dyed anodising of this interior is a thing of the past. Coloured anodising, however, remains readily specifiable. Where Harvey used coral and silver anodising, Make have opted to unite the new aluminium elements, such as the pressed and cast aluminium escalator casing by Crosstec of Hong Kong, by using the same Nickel Bronze 'Liquid Metal' finish - it is very beautifully and consistently applied. Make view the escalators 'rather than [being] purely functional,' as being 'expressed as sculptural forms in the space accented by the curving, fluting and feathering of a bespoke cladding design.'[17] Services are carefully integrated into the Grigio Ginevra marble walls behind new hinged silver anodised aluminium extrusions – taking on the role played by the 'Imprest' Aluminium wall components of the 1930s fit-out. The Make team comprised: Katy Ghahremani, Grigor Grigorov, Regine

Fig 6.14 Make's core design team for Harrods Esculator Hall Five, snagging in the winter of 2016

Fig 6.15 Harrods Escalator Hall Five, 1938

Fig 6.16 Detail of the liquid-metal coated aluminium facade screens

Kandan, Justin Lau, Ian Lomas, Mehrnoush Rad, Jack Sargent, Ken Shuttleworth, and Tracey Wiles.[18] All elements of the reinvented interior, be they new or old, speak of quality and care for detailing.

Fig 6.17 Make's section through Harrods Escalator Hall Five

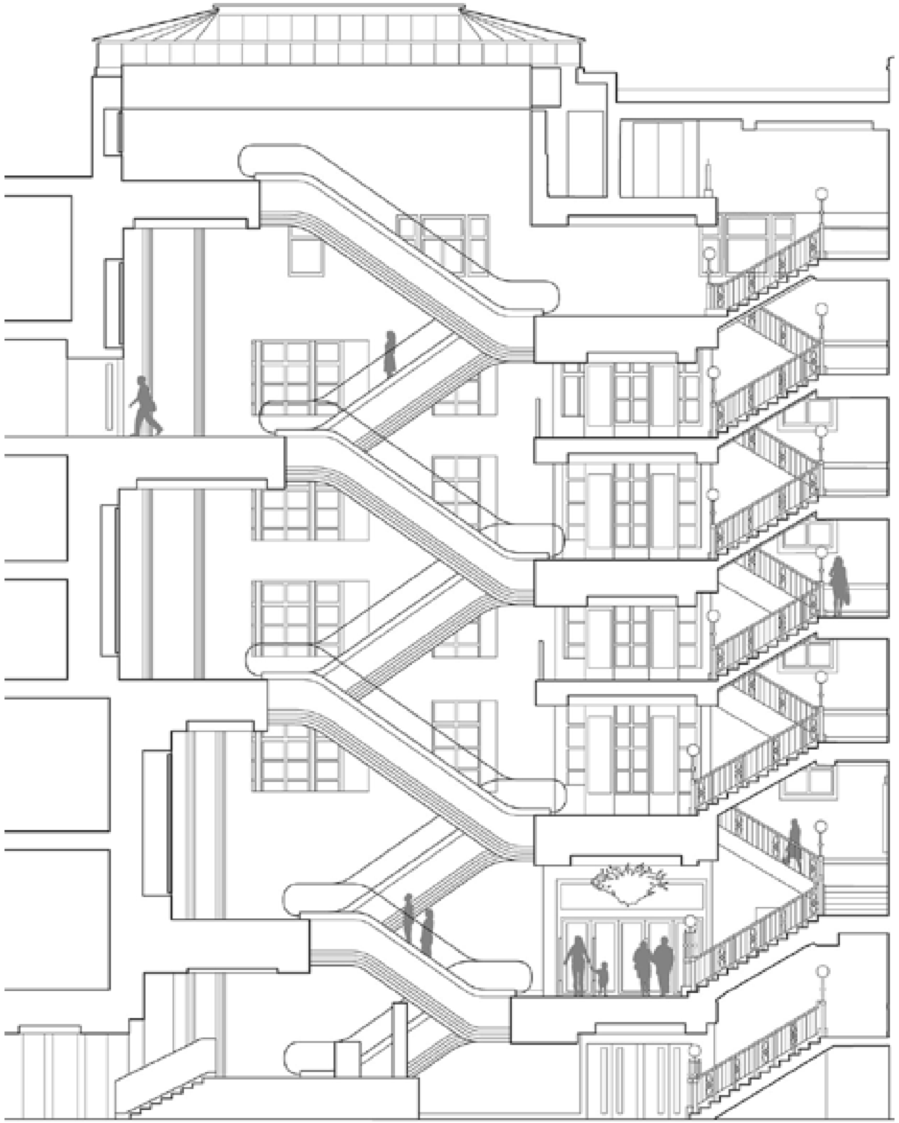


Fig 6.18 British Aluminium CO. in 1938

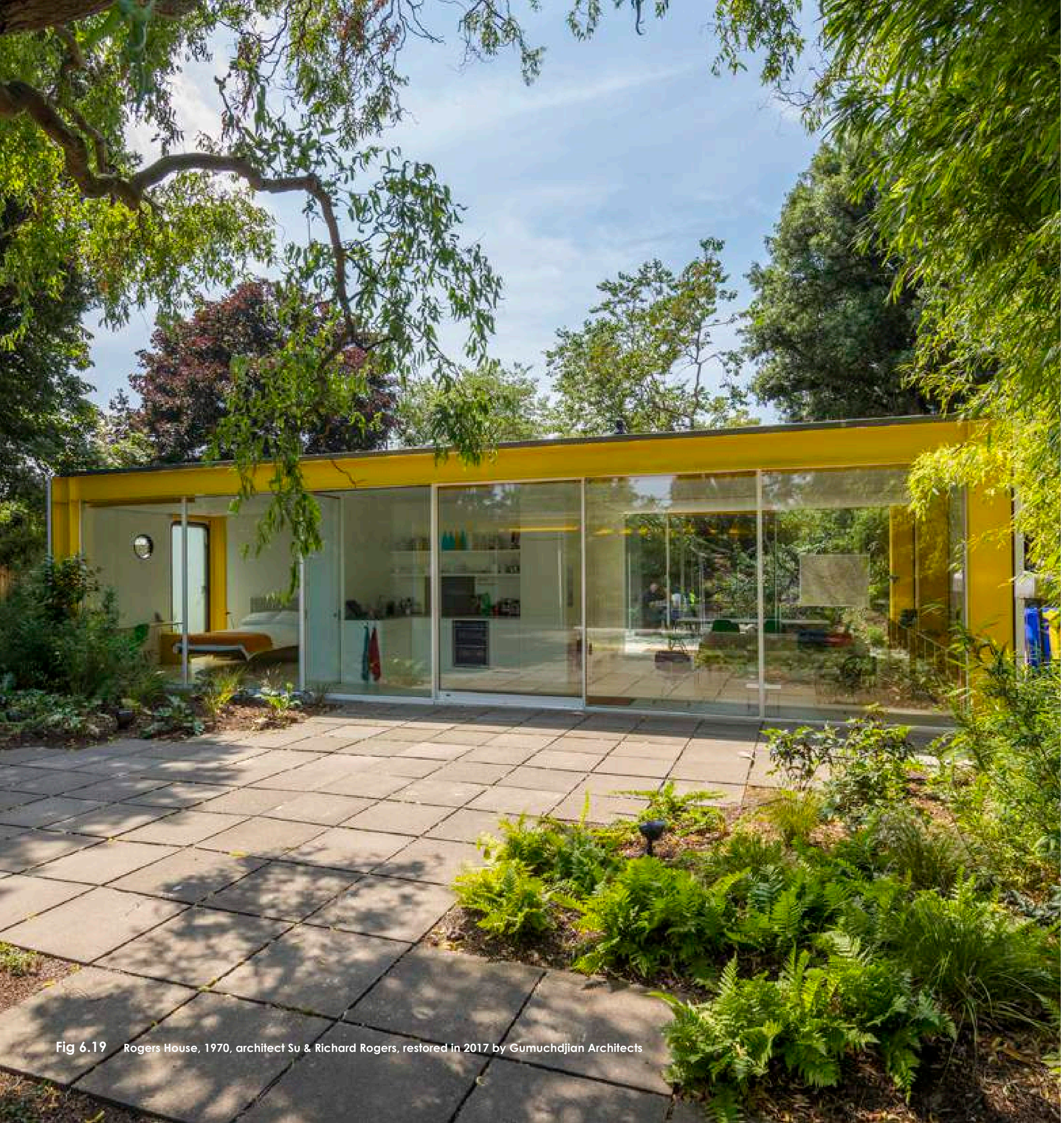


Fig 6.19 Rogers House, 1970, architect Su & Richard Rogers, restored in 2017 by Gumuchdjian Architects

Rogers House, London, England: Architect Richard and Su Rogers, 1970, Restoration: Gumuchdjian Architects, 2017

The Rogers House, 22 Parkside was designed by Su and Richard Rogers for his parents Nino and Dada Rogers, on a suburban site near Wimbledon Common in South London. It was designed in 1968 and completed in 1970. Inspired by the Case Study Houses, in post World War Two California, which were promoted by Art & Architecture magazine, edited by John Entenza. Thus, the Rogers House takes typological inspiration not from its neighbours but Case Study House Eight by Charles and Ray Eames (1949), as it also comprises a house and studio separated by a courtyard, with a common plan width and common height yet varied in size to match the spatial requirements.

The Rogers House is on a wedge-shaped site, with two elegant blocks of accommodation that face South West towards the road, with Wimbledon Common beyond. The landscape is integral to the design, and the spatial sequence from the road means you immediately pass through a protective gentle berm, where you first reach the studio (or lodge), and further a courtyard space, which separates the main house opposite. Beyond the main house is a private rear garden. Generous planting surrounds the Rogers House, which is now mature, and in satellite photographs the site almost looks like a gap in the suburban fabric of London. 'It comprises two structures, the house and lodge, arranged with three distinct outdoor spaces and an 'enfilade' enhanced by Rogers' use of wide span steel portals and fully glazed façades,', observes Chris Foges.[19]

Richard Rogers worked closely with engineer Anthony Hunt on the design of the steel structure of the studio and house. Having worked with him previously on the expressed external steel structure of the Reliance Controls Electronic Factory in Swindon (1967), in partnership with Norman and Wendy Foster and Georgie Wolton, practicing as Team 4. Reliance Controls, although a seminal democratic and flexible industrial building, 'was demolished in 1991 despite a televised local appeal for its preservation because of its originality and historical importance.'[20]

The restoration of the Rogers House was entrusted to Philip Gumuchdjian of Gumuchdjian Architects. 'I first saw the building in 1980, when I had just started working for Richard [Richard Rogers Partnership] and sent round to fix a blind', he recalls. 'I had never seen – or even imagined – a space like it.' '[21] Philip Gumuchdjian deepened his knowledge and skills in delivering architecture whilst working for Richard Rogers + Partners, where one of his roles was to act as Richard Rogers amanuensis.

The studio and house use the same structural system of 13m wide steel portal frames, comprising rolled steel joists (RSJs) 360 × 170mm. The studio has three portals spaced at 3.4m centres and the house has five portals at the same centres, all are painted bright yellow. Su and Richard Rogers insisted that these portals were as slender as possible and of totally consistent depth. Anthony Hunt described this design challenge to Neil Jackson paraphrasing Richard Rogers,

Fig 6.20 Rogers House, 1970, restored in 2017

'come on Tony, you can make it work, you can make them all the same'.[22] Noting the end portals are carrying less roof load, Hunt pulled it off and there is no discernible difference in the portals. Neil Jackson describes the outcome 'as a clean, brightly coloured through-space, the Rogers House works supremely well.'[23]

In 2013 Historic England (formerly English Heritage) added the

Fig 6.21 Rogers House photographed in 2017

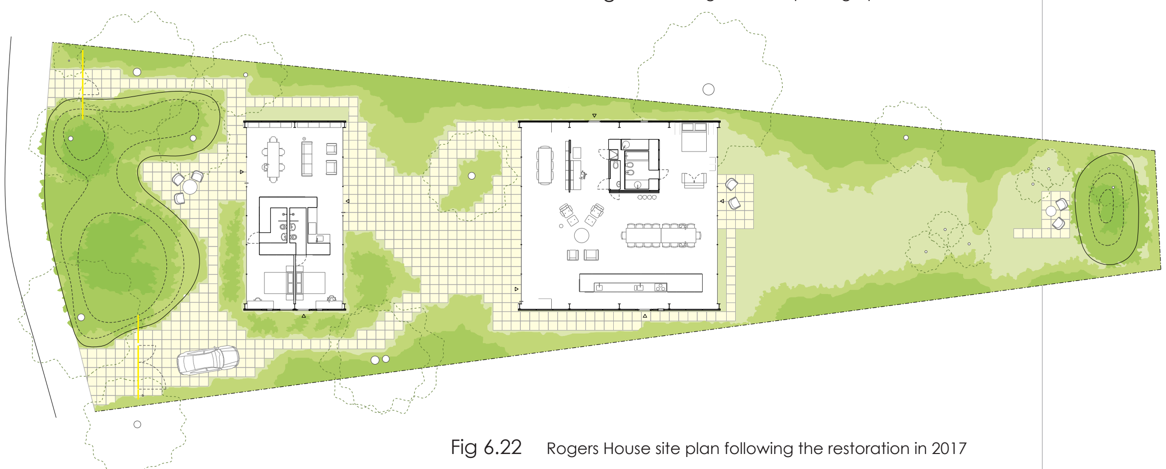


Fig 6.22 Rogers House site plan following the restoration in 2017

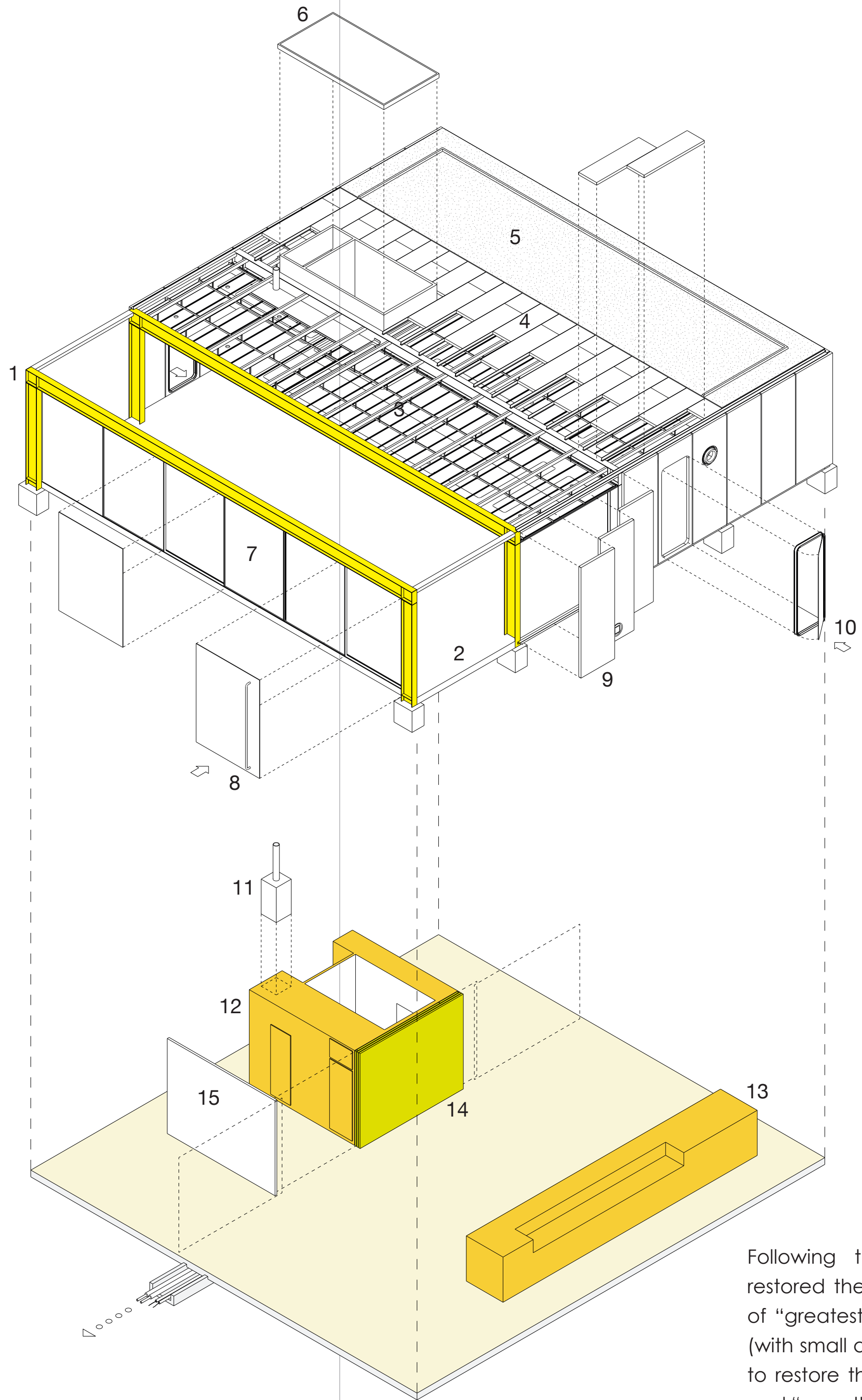
Rogers House to its listing as Grade II*.[24] Citing its historic significance it is a 'surviving early British High-Tech building', which included 'experimental use of materials and techniques: in particular factory-finished components and dry construction'.[25] The listing states the 'south-east and north-west walls are fitted with white PVC-coated smooth aluminium sandwich panels with a plastic core, which are completely prefabricated, and linked together with a neoprene zip jointing system.'[26] Historic England also praises the legibility of the design, which is characteristic of all of Richard Rogers' projects.

The Rogers family has gifted 22 Parkside to Harvard University's Graduate School of Design (GSD) as a residence for graduates studying architecture in London. Gumuchdjian Architects' design team for the restoration included: landscape architect, Todd Longstaffe-Gowan, structural engineer, Techniker, services engineers Atelier Ten (competition) Aecom Northern Ireland (implementation). Matthew Wells of Techniker, structural engineer for this restoration project, originally worked for Anthony Hunt.

Originally clad in a 51mm (2") thick insulated panel faced on both sides with aluminium skins finished in 200micron white ICI Novolum PVC, which had a textured finish. These panels were fabricated in the USA by Aluminium Company of America (Alcoa), using a timber frame and insulating polyurethane cores, with Asbestolux (asbestos based) linings behind the aluminium skins. These panels had been developed for refrigerated truck bodies.

Neil Jackson describes these panels as an example of technology transfer that looked sophisticated.[27] John Young (a long term collaborator of Richard Rogers) in conversation with Neil Jackson sets out his thinking: 'Instead of putting up a single sheet of corrugated steel and then a liner, you get a completely prefabricated, pre-finished panel and even though the Rogers House was steel construction and very precise, nevertheless the panel system was even more precise.'[28] John Young is named as part of the design team in Historic England's listing of the Rogers House.[29] This set of ideas led to the practice's gasketed monocoque panel based design of the ZipUP House, which eliminated the need for a structural frame. This house was designed as an entry to the 1968 Du Pont Company's 'House for Today' competition, and it has become an iconic design within world architecture, despite only achieving second place in this competition.[30] John Young believed the competition jury considered it 'too futuristic' and thus it remained unbuilt. [31]

Fig 6.23 Gumuchdjian Architects Isometric drawing of the restored Rogers House



Assembly: The 1968 Rogers House
Restored 2015-2017 by Gumuchdjian Architects

1. Structure - 5 welded rigid RSJ portals of 360x170mm, spanning 13m on 3.4m grid. Redecorated to match original colour BS2660 0-001 Canary.
2. Floor - reinforced concrete slab, finished with self-levelling white polyurethane throughout. Cleaned and waxed.
3. Heated Ceiling & Lighting - original 'Stramax' suspended heated ceiling system, fully reinstated and served by new independent combination boiler. New bespoke flush ceiling lights throughout, to reinstate 1968 design. Low-e aluminium-foil blanket added over ceiling to aid heated ceiling performance.
4. Roof Deck - replacement wood-wool slabs over new supporting steel channels.
5. Roof Covering - new high-performance rigid vacuum insulated panel (VIP) insulation, covered with cut-to-fall PIR insulation with fully adhered single-ply roofing membrane.
6. Roof Lights - replacement double-glazed roof lights over bathroom and bunks.
7. Steel Glazing Mullions - redecorated, gloss white.
8. Glazing - full-height fixed double glazing and 12mm toughened sliding doors. Original Henderson sliding door components fully refurbished.
9. Wall Panels - New 75mm thick wall panels comprising 2mm thick aluminium inner and outer skin, finished matt white RAL9016 PPC, with a core of 30mm rigid insulation framed by thermally-broken aluminium extrusion, and 2 layers of A1-class fire board providing 60-minutes fire resistance. Panels are 'zipped' together with EPDM gaskets at the vertical seams and EPDM-sealed at gable ends. New services are fully integrated. Original bus-like doors, windows and vents have been serviced and reinstalled.
10. Wall Panel Doors & Windows - refurbished and reintegrated aluminium-framed bus-like glazed doors and windows, closing into new continuous EPDM gasket-sealed openings.
11. New combination boiler supplying heat to the radiating ceiling system and bathroom radiator.
12. Fully serviced fixed pod containing bathroom, WC, shower cubicle, laundry, and deployable bunk beds. Restored and redecorated to match original colour BS2660 0-003 Golden Yellow.
13. Fully serviced fixed island unit containing the kitchen and storage cupboards, restored and redecorated to match original colour BS2660 0-003 Golden Yellow.
14. Full height sliding partitions, redecorated to match original colour BS2660 0-008 Chartreuse.
15. Fixed partition dividing the spare bedroom and study, restored and redecorated white satin. Vitsoe 606 shelving reinstated.

Following the best principles of ICOMOS,[32] 'Gumuchdjian restored the organisation of the buildings to that of the period of "greatest significance", from the mid-1980s to the late 1990s (with small alterations, such as en-suite bathrooms) and has tried to restore the fabric while retaining some of the patina of age and "something of the poetic quality the parents created by their inhabitation of the house."'[33]

‘ ‘Opening’ up works revealed the trial and error nature of the original construction, and later remedial works – neither of which detract from the buildings’ quality,’ say Gumuchdjian ‘it was a prototype, not the finished thing, this is the one where the panels failed three times, a real experiment.’[34] In the restoration of the Rogers House, 13m wide steel portal frames have been cleaned and repainted, as have the steel mullions of the end wall glazing. In these elegantly transparent end walls, the original single glazing has been reinstalled and even the glazed sliding doors are original having been very carefully disassembled, serviced and reinstalled. The insulated building fabric, which wraps the house and studio over the steel portal frames, has been renewed to provide better and thus lower U-values, removing asbestos-based components and providing more reliable waterproofing and, in the wall panels, a new durable finish.

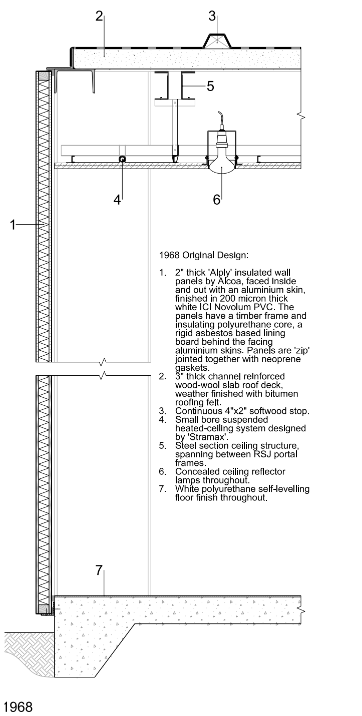


Fig 6.24 Rogers House - wall section 1970

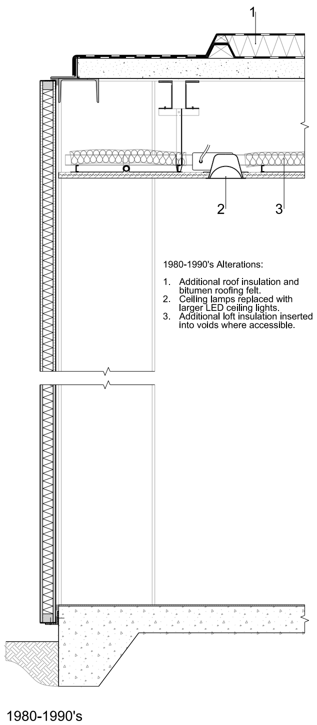


Fig 6.25 Rogers House - wall section 1990s

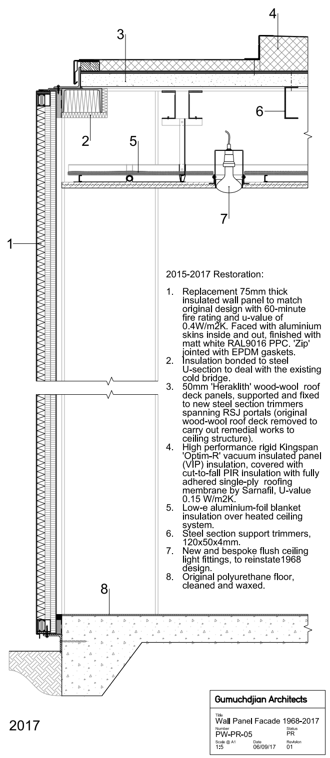


Fig 6.26 Rogers House - wall section 2017

Fig 6.27 Rogers House: polyester powder coated aluminium panels with replacement EPDM gaskets, 2017

A new build-up has been developed for the construction of the 75mm thick wall panels, comprising two-millimetre inner and outer skins of aluminium with a white textured polyester powder coated finish, on an insulating core of 30mm of Styrodur® (an extruded polystyrene insulation manufactured by BASF) framed by thermally broken aluminium extrusions, this is backed up by two layers of Ridurit®, which provides fire resistance. Ridurit® class A1, non-combustible glass reinforced gypsum board manufactured by Saint-Gobain. Overall the panel is rated for 60minutes fire resistance, integrity, stability and insulation. The new wall panels provide an overall U-value of 0.4 W/m²K. The original bus-like gasketed windows have been reinstalled into the new panels, now sealed with durable EPDM gaskets.

Fig 6.28 Rogers House, 2017, detail of the polyester powder coated aluminium wall panel meeting the painted steel portal frame

Michael Ramwell, project architect for Gumuchdjian Architects, carefully coordinated the diversity of windows, entry system and services into the bespoke panels, which were fabricated by Aluprof using its MB-59S system. Michael Ramwell is an award winning MArch Graduate of the MARS studio at The University of Nottingham School of architecture, and he was hired by Philip Gumuchdjian for his design skills and his knowledge of aluminium, which he gained whilst working as a researcher/future architect at Michael Stacey Architects on the TSC research programme and especially on TSC Report Four, *Aluminium: Flexible and Light*.

The U-value of the roof has been enhanced to 0.15W/m²K. The innovative ceiling-based heating systems has been retained, however, its performance has been enhanced by the placement of aluminium-foil blanket insulation over the heating coils in the discrete ceiling void, which is coordinated to the depth of the steel

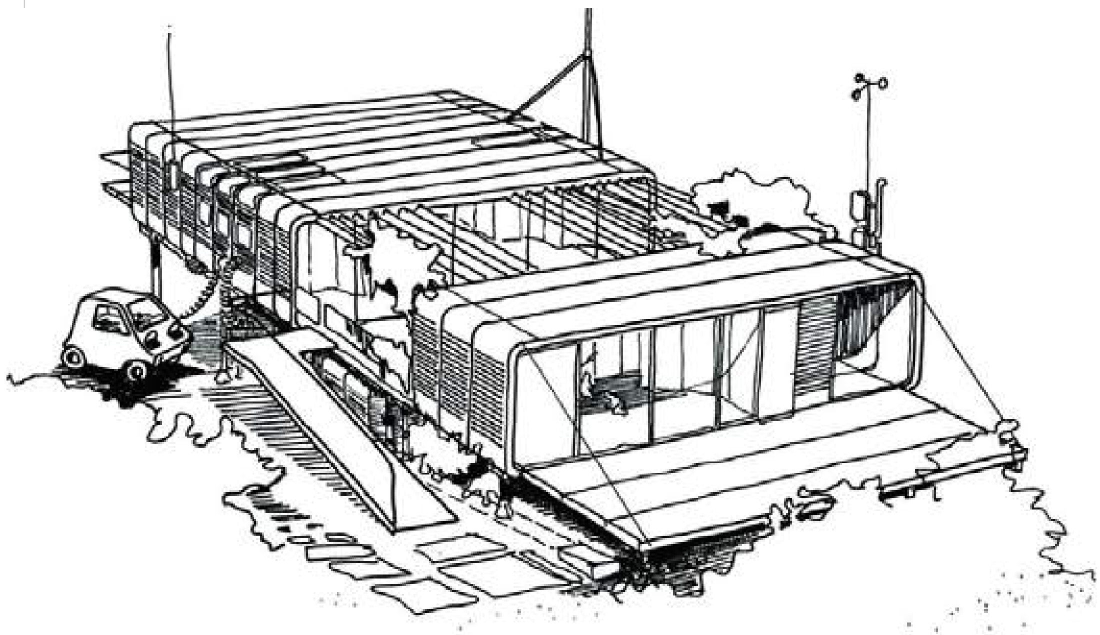


Fig 6.29 ZipUp House, Richard and Su Rogers, 1968

portal frames. A key task in the restoration of the Rogers House was to minimise cold bridging through the structure and building fabric without comprising the reading of this listed building. Noting that in metal based construction cold bridges often act as 'warm fingers', conducting heat out through the building fabric, rather than posing a risk of condensation. Figures 6.22–6.24 shows the comparative before and after sections through the construction of the house. Note how the final steel U-section at the head of the external wall panels has been wrapped with insulation to prevent it acting as a 'warm finger'.

Fig 6.30 Rogers House: now a home from home for Harvard's GSD, 2017

The polyester powder coating to the aluminium panels has an unusual textured finish, which was developed with Aluprof to closely match the original texture of the original white ICI Novolum PVC,

'We do more research than most private offices – we are very technologically oriented.'
Richard Rogers interviewed about the Rogers House in the Architects Journal, 6 October 1971

Fig 6.31 **Rogers House photogrphed in 2017**

Fig 6.32 Rogers House, 2017

but is only 100μm compared to the original thickness of 200μm. The polyester powder coating is in accordance with Qualicoat Class One, with a guarantee of 25-years. Where normally an architect or specifier wants to ovoid the 'orange peal effect' of thicker polyester powder coating – this is precisely what was required on the Rogers House to match the original finish. A constant reality in material science and material culture - one person's failure is another's success and thus many of the rules of thumb stated about materials are almost never true. Rather an understanding from first principle and an understanding of the desired outcome and performance are essential. Dean of the GSD, Mohsen Mostafavi, described the restoration as 'a painstaking process akin to repairing a watch'.[35] Philip Gumuchdjian believes that GSD was vital in the successful delivery of this project, 'It would have been easy, with another client, to have lost this building in the process of restoring it.'[36]

The house still has the original furniture chosen by Nino and Dada Rogers and their son Richard: including steel and aluminium modular shelving designed by Dieter Rams and still supplied by Vitsœ.[37] The Historic England listing observes: 'The house made a feature of their collection of furniture by Ernesto Rogers and Charles Eames.'[38] Although today we would always credit both Charles and Ray Eames.

The Rogers House has a spatial, tectonic and even poetic clarity that is rarely seen and experienced in contemporary architecture. Arguably the spatial and tectonic diagram of the Rogers House inspired the Sainsbury Centre of the Visual Arts, Norwich (1978) designed by Foster Associates, now Foster + Partners, which Norman Foster led and again Anthony Hunt was the structural engineer.[39] Some 50years on from its completion, collectively, we are still learning from this design by Su and Richard Rogers, with John Young. Undoubtedly, Harvard's graduates will enjoy living in this seminal house and one would hope that they draw inspiration from it, rather like Rome Scholars, but in a suburb of Londinium.

Needle Tower II, Kröller Muller Museum, Otterlo, Netherlands: Artist Kenneth Snelson, 1969

Needle Tower II is one of a series of tensegrity structures designed by Kenneth Snelson. In a tensegrity structure the compression elements, aluminium circular hollow sections, and the tension system of stainless steel wires are totally discrete yet create a balanced equilibrium of forces and thus a stable structure. 'The forces are made visible' observes Eleanor Heartney.[40] Needle Tower II was assembled at the Kröller Muller Museum in Otterlo during 1969. It is assembled from 24 four-strut tensegrity modules and stands at 30m, although it appears to be taller, because of the small scale of the modules and the tower's slender taper.

The origin of tensegrity structures dates to a serendipitous meeting in the summer 1948, when Snelson was a student at Black Mountain College where he met Richard Buckminster Fuller, a late replacement tutor.[41] He chose Snelson to make structural models for his lectures. Heartney considers Black Mountain College, founded in 1933, 'an exemplar of the progressive educational principles of John Dewey and the Bauhaus.'[42] Sneslon returned to the University of Oregon in the Fall where he made *Early X Piece* (1948) formed of two wooden x-forms held, without touching, by nylon wire. He later described this as 'continuous tension, discontinuous compression structures.'[43] P. Silver, W. Mclean and P. Evans note that: 'During his time as a student, Snelson developed and formalized the structural innovation of tensegrity structures'.[44]

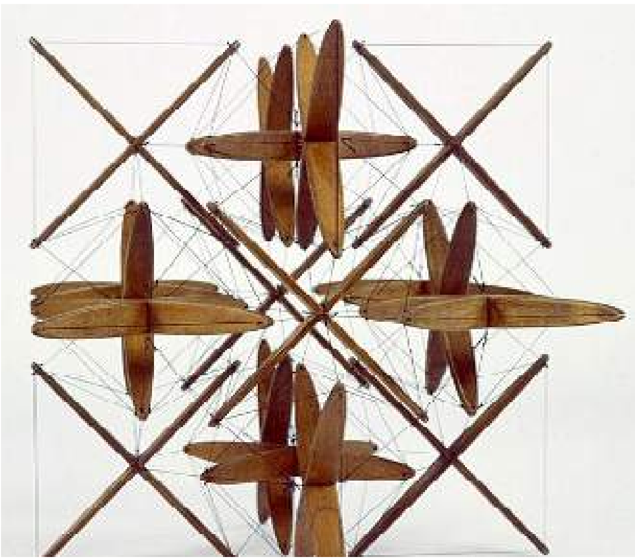


Fig 6.33 Kenneth Snelson 's X-Piece, 1948

Fig 6.34 Kenneth Snelson 's Needle Tower II, 1969

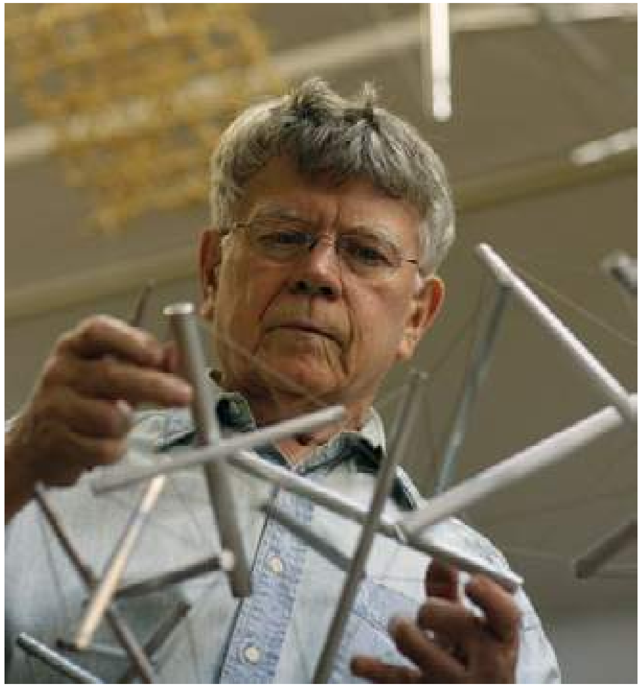
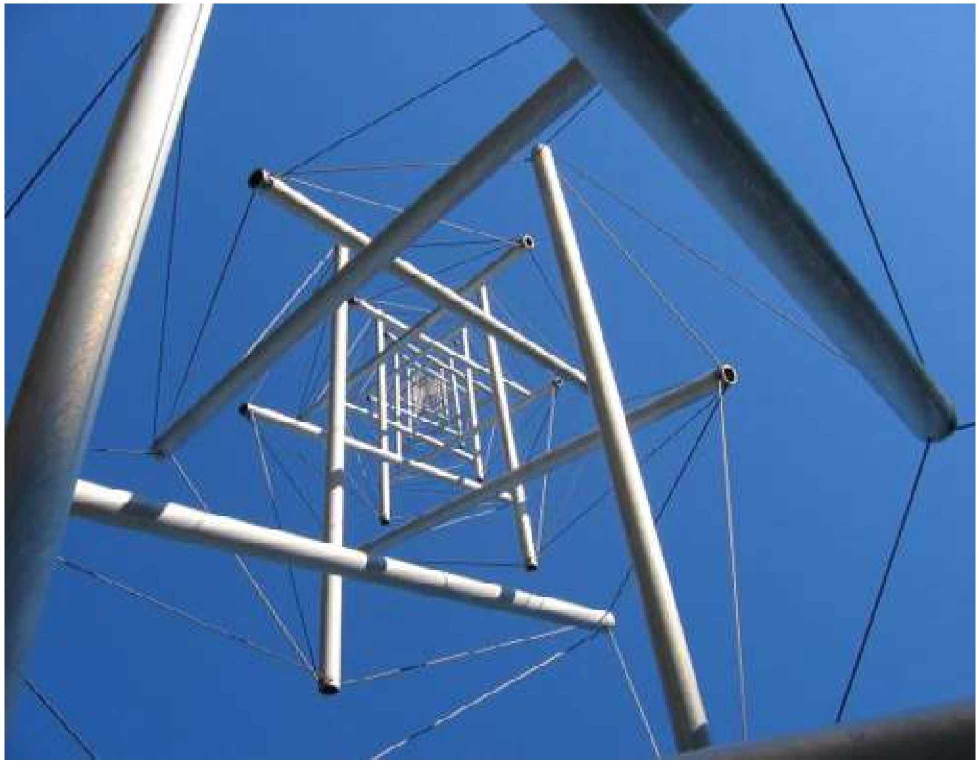


Fig 6.35 Kenneth Snelson, courtsey of the New York Times



On his return to Black Mountain College in summer 1949 Snelson 'showed his new sculptures to Fuller, who immediately recognised their potential, and, Snelson feels, adapted them into his work without credit to Snelson', records Heartney.[45]

Someone of the pioneering genius of Richard Buckminster Fuller should not need to absorb the work of a brilliant student without crediting him. However, putting this to one side, Snelson's tensegrity structures possess a beauty born out of the clarity of the distribution of forces – a balanced equilibrium that is apparent to all onlookers.

Don E. Ingber, a founding Director of the Wyss Institute, is a leader in the emerging field of biologically inspired engineering. Speaking at the Adaptive Architecture conference in the Building Centre (2011) he recalled that as an undergraduate student he took a fine art and sculpture minor as part of his degree.[46] During this course he learnt about the tensegrity structures invented by Kenneth Snelson. Later in his career he realised that cells act like tensegrity structures. Ingber realised that: 'An astoundingly wide variety of natural systems, including carbon atoms, water molecules, proteins, viruses, cells, tissues and even humans and other living creatures are constructed using a common form of architecture known as tensegrity.'[47]

Stacey and Stacey observed at the Adaptive Architecture conference that 'Ingber has made major contributions to cell and tissue engineering, angiogenesis and cancer research, systems biology, and nanobiotechnology. He was the first researcher to recognize that tensegrity architecture is a fundamental principle in the way living organisms are structured at the nanometer scale.'[48] Thus Ingber's discovery is a rare if not unique example of technology transfer from art and architecture into cell biology. However, the Wyss Institute is dedicated to the bio inspired or technology transfers, arguably, in the other direction – from the natural world into engineering and architecture.

Fig 6.36 Kenneth Snelson 's Needle Tower II, 1969

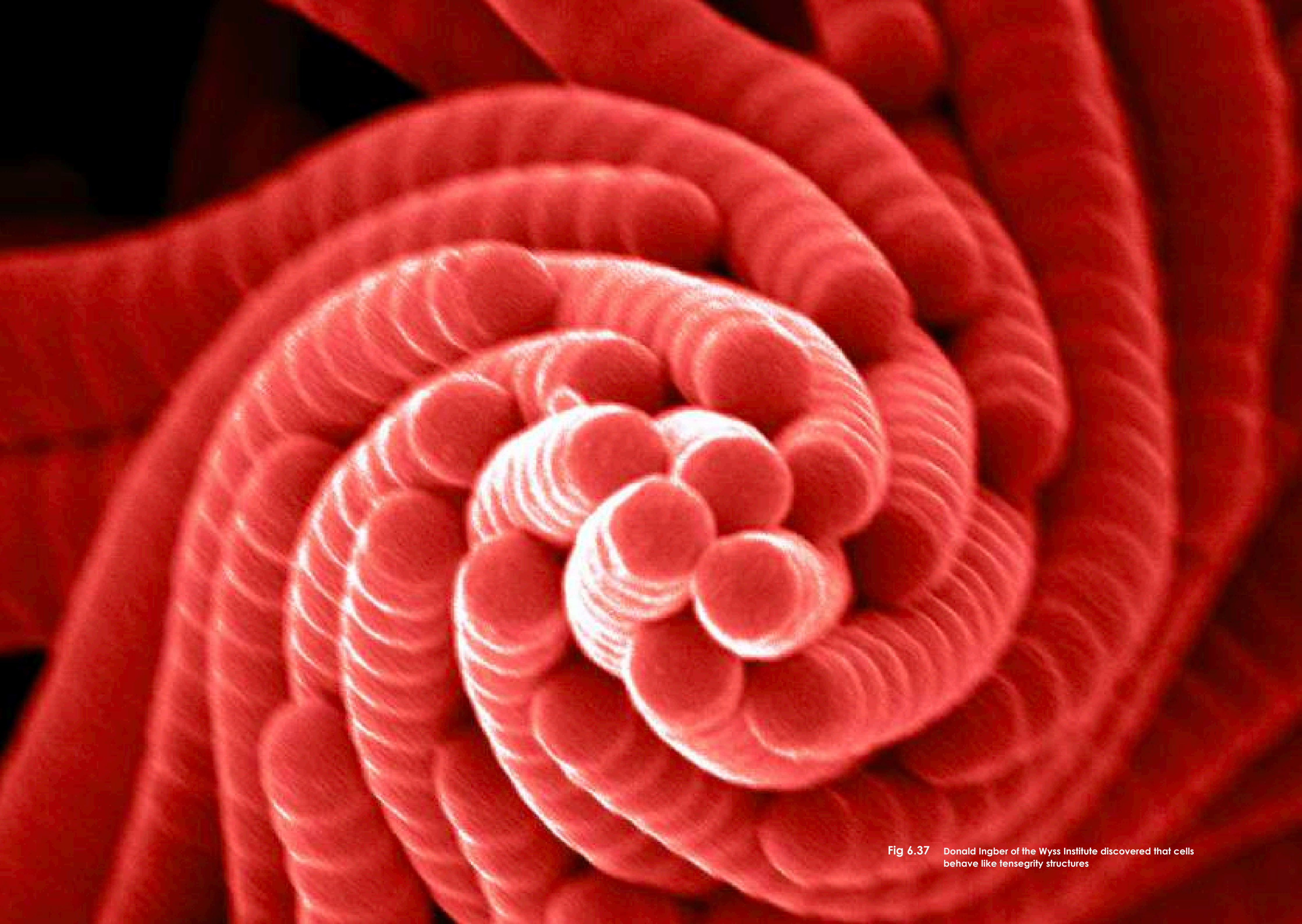


Fig 6.37 Donald Ingber of the Wyss Institute discovered that cells behave like tensegrity structures

Mercedes-Benz Museum, Stuttgart, Germany: Architect UN Studio, 2006

UN Studio of the Netherlands is the architect of this digitally designed temple-to-the-automobiles, which were made in Stuttgart by Karl Benz and Gottlieb Daimler and their corporate descendants. The Mercedes-Benz Museum is located immediately outside their factory in Stuttgart and within viewing distance of the home of VFB Stuttgart football club – the Mercedes-Benz Area. The plan form of the museum is a digital elaboration of the three-cornered star that is the heart of this car company's bonnet badge and corporate logo. The star is transformed into three circles that intersect to form a cloverleaf plan; this in turn generates a ramp from which all gallery spaces can be seen. The building is a New York Guggenheim for the digital age; in which UN Studio pay homage to Frank Lloyd Wright.

Fig 6.38 Mercedes-Benz Museum, Stuttgart, Germany, 2006

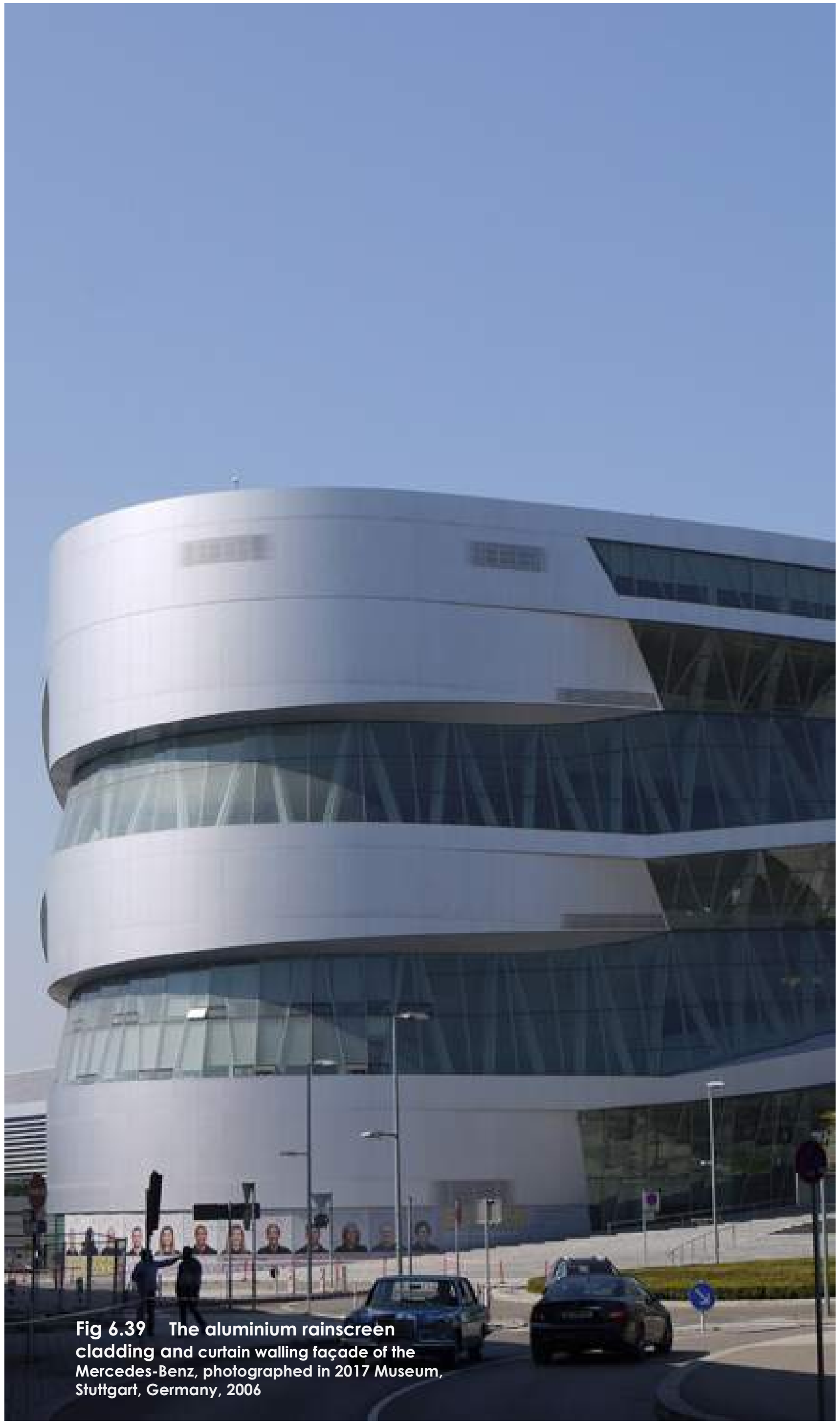


Fig 6.39 The aluminium rainscreen cladding and curtain walling façade of the Mercedes-Benz, photographed in 2017 Museum, Stuttgart, Germany, 2006

Fig 6.40 Looking up the atrium of the Mercedes-Benz Museum, Stuttgart, Germany, 2006

Following a sweeping ramp through the spatially generous atrium visitors are almost immediately transported to the top of the museum by Fritz Langesque silent silver lift pods. The exhibition opens with a quotation attributed to William II 'I do believe in the horse. The automobile is no more than a transitory phenomenon'.[49] The journey through the museum starts with the beginnings of the automobile and the first steps taken by Mercedes & Benz, with the past at the top and the present and even the future at ground level. The cars, trucks and even bicycles produced by Mercedes-Benz are accompanied by imagery, politics, society and technology of the time, from the Suffragettes (1903) to the first test tube baby, Louise Brown, born in Oldham, England, in 1977.

UN Studio has clearly taken inspiration from Mercedes-Benz and car technology, but not in a slavish manner. The primary structure of the museum is beautiful in-situ concrete. However, the lining of the gallery is a seamless skin off-white air bag material stretched onto an anodised aluminium framework, which becomes apparent only as it frames display cabinets. In this museum the architects match their seamless computer modelling with inventive tectonics and componentry.

The stars of the show are the vehicles and aeroplanes: from

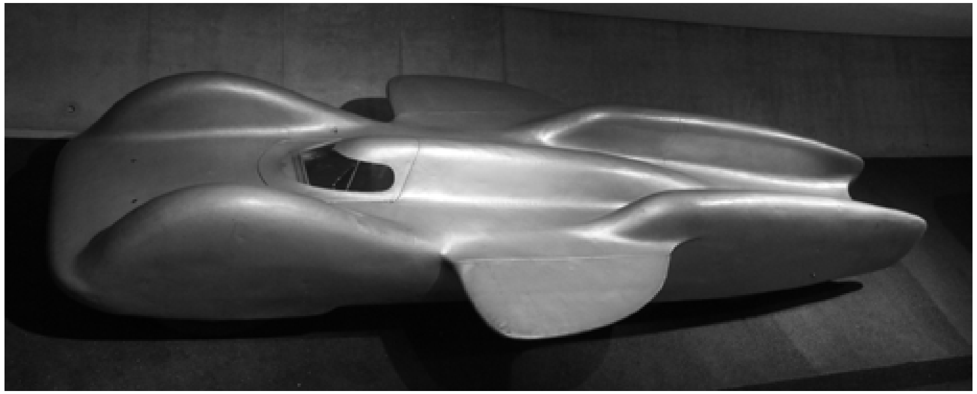
Fig 6.41 A Mercedes-Benz bicycle – *a refined semi roadracer*, manufactured during the interwar period of hyperinflation in Germany (1924-1926)

Fig 6.42 Mercedes-Benz Museum, Stuttgart, Germany, 2006, architect UN Studio

Fig 6.43 Mercedes-Benz WeltreKordwagen T 80, designed by Ferdinand Porshe, 1939

early cars with lightly integrated diesel and petrol engines, to beautifully articulate cars of the 1930s, and sleek monocoques of contemporary Formula One Grand Prix winning racing cars. Stand out exhibits include: the refined semi-road racer bicycle and the WeltreKordwagen T 80. Mercedes-Benz turned to producing bicycles during the interwar period, at a time of hyperinflation (1924-1926), to reduce its dependence on automobile production. The Mercedes-Benz WeltreKordwagen T 80, designed by Ferdinand Porshe, 1939, is a world record car with a streamlined hand beaten mill finish aluminium body. It wasn't able to attempt the world land speed record as the Second World War began before it could be taken to the Bonneville Salt Lake Flats in UtAh, USA. Monocoque

Fig 6.44 Mercedes-Benz steel tubular space frame,1952



shells now dominate motor racing, offering integrated lightweight structure and skin. However, the elegance of this steel tubular space frame from 1952, when Mercedes-Benz returned to motor racing, remains compelling in its visual clarity.

The Mercedes-Benz Museum is clad in curtain walling and 4mm thick aluminium rainscreen cladding. The cladding is embossed and finished with 40µm of Duraflon, designed in response to UN Studio's drawings and specification, it was installed by Joseph Gartner, which is now part of the Permasteelisa Group. Duraflon is a fluoropolymer coating, and considerable investment was made to develop prototypes, which were key to achieving UN Studios desired reflectance for this finish. The architect was striving to finish the building as beautifully as the Mercedes-Benz cars in the factory next door and within their own museum.

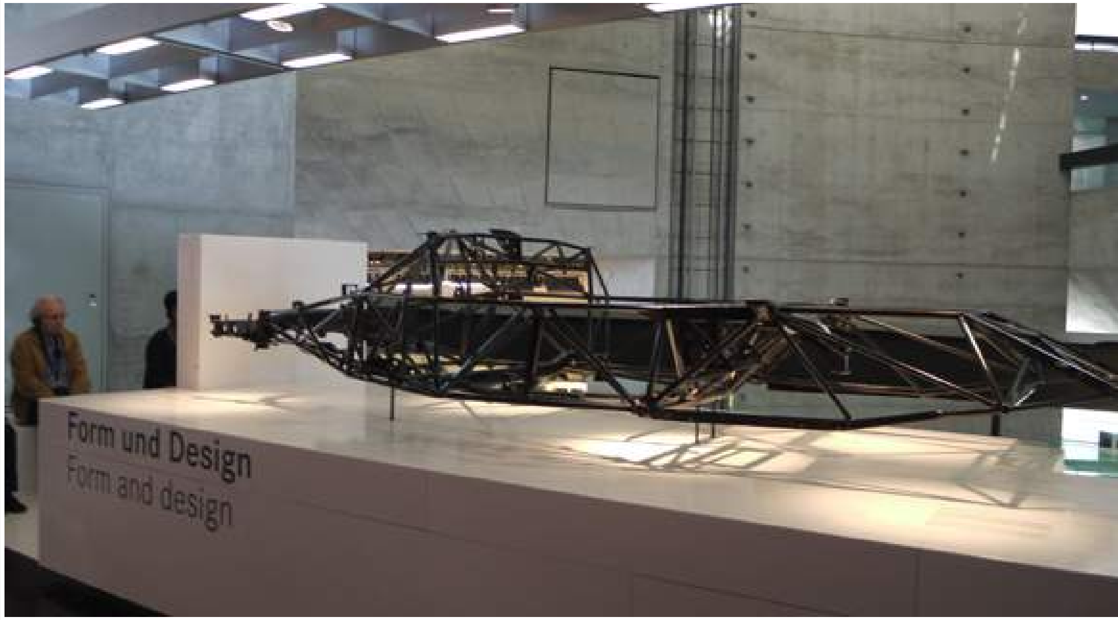


Fig 6.45 Mercedes-Benz Museum, Stuttgart, Germany, 2006

If the history of the automobile is not enough, before leaving, a visitor can dine elegantly, buy toy Mercedes-Benz cars for his or her children and even buy a new or classic Mercedes-Benz. For some visitors, the elegance of the aluminium rich architecture and its contents are sufficient to satisfy one's sensibilities.

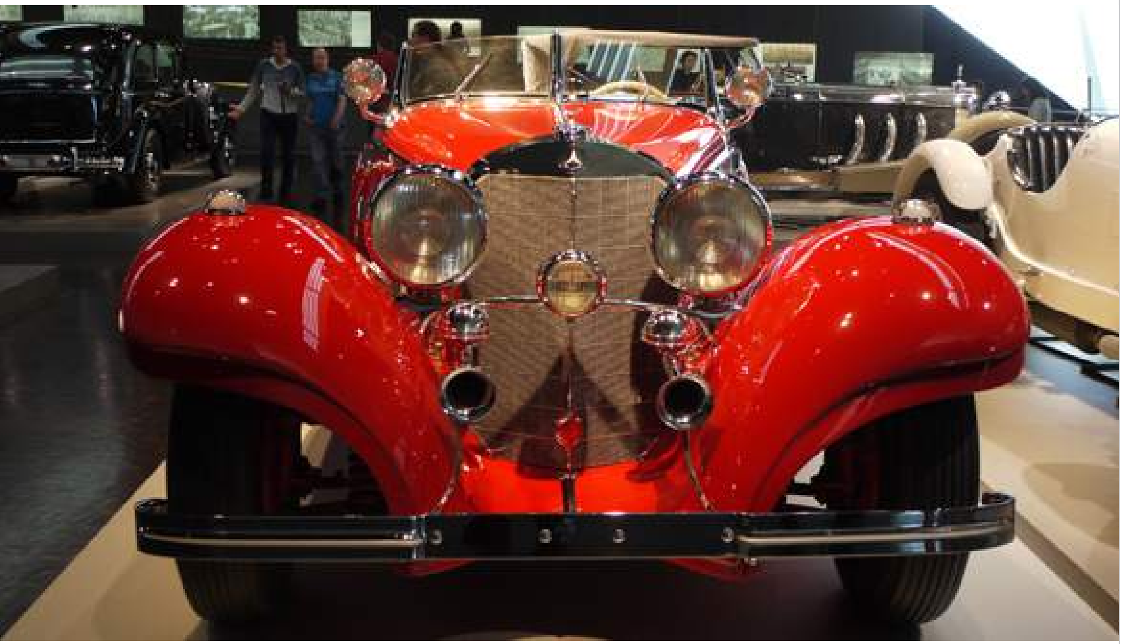


Fig 6.46 A Mercedes-Benz, 500K Spezia-Roadster, 1934–1939

Fig 6.47 A Mercedes-Benz, 300 SL Coupé, 1955

Fig 6.48 Typical gallery level in the Mercedes-Benz Museum

Fig 6.49 Mercedes-Benz Museum, Stuttgart, Germany, 2006, architect UN Studio

Mallorca Congress Centre, Palma de Mallorca, Spain: Architect Francisco Mangado, 2008

The composition of the Mallorca Congress Centre is formed of two major elements that fold out along the north and south façades. Francisco Mangado describes this as 'two stretches of wall devoid of physical density but endowed with functional and architectural relevance. The one facing northwards contains all the facilities that complement the main programme, as well as the supplies and staff access areas. But the most important one, [is] the one facing south and towards the sea'.[50] This folded façade looks due south across the Balearic Sea, part of the Mediterranean Sea, towards North Africa. Francisco Mangado has not designed gentle 'seaside architecture'; this is a bold response to the large scale of this hotel and congress centre, and the fierce or delightful Mediterranean sun. The mean daytime temperature in Mallorca ranges from 12 degrees Celsius in January to over 26 degrees Celsius in August. The Congress Centre's façade is four meters deep, sheltering the interior from sun yet affording sea views. Mangado combines a sense of depth and shadow play in this façade, yet it is weightlessness by cladding the fin walls in foamed aluminium rather than stone. Foamed aluminium is a cast product. The cast aluminium panels of the Ljubljana Television Centre, in Slovenia, by architect France Rihtar in collaboration with Branko Krasevac, who designed the façades,[51] are precedent for the cladding of this congress centre. TSC Book Two, *Aluminium Recyclability and Recycling* demonstrates that there is a more extensive use of cast aluminium in architecture than conventionally considered.[52]

Stabilised foamed aluminium is cast by CYMAT Technologies of Ontario. In a process, developed in the late 1990s by Alcan International, air is injected into molten aluminium, which contains a fine dispersion of ceramic particles. CYMAT state 'these particles stabilize the bubbles formed by the air, much like dry cocoa powder stabilizes bubbles when added to milk'.[53] This is the material science inverse of a best practice in casting metals, where every effort is made to eliminate voids in the casting, with the aim of creating the best possible integrity in the component. CYMAT's process enables them to produce aluminium foam which is only 2.5% aluminium with a bulk density of only 68 kg/m^3 compared to 2760 kg/m^2 for aluminium itself. A section held in your hand would weigh significantly less than a comparative sized chocolate 'Aero' bar, which it resembles. The thermal conductivity of 2.5 per cent aluminium foam is 0.028 $W/m^{\circ}C$ that compares to 0.037 $W/m^{\circ}C$ for mineral wool insulation with a density of 24 kg/m^2. It is possible to produce aluminium foam in a range of bulk densities from 20 to 2.5 per cent. The density is controlled by the average cell size and average wall thickness. At 20 per cent the average cell size is

Fig 6.50 Mallorca Congress Centre, Palma de Mallorca, Spain, architect Francisco Mangado, under construction, it was completed in 2008

3mm with an average wall thickness of 86 μm; at 6 per cent this is 9mm and 50 μm respectively.[54] CYMAT produce stabilised foamed aluminium for a range of applications, including the military. For architectural applications CYMAT use the trade name Allusion. CYMAT's standard panel size is 2440 × 1220mm (8' × 4') with a range of panel thickness, including 12.7mm (½") 25.4mm (1") and 43.2mm (1.7"). They offer three finishes: as cast panels, with skins on both faces; panels with one machined face, with open cells; and a translucent open cell panel where both faces have been machined. The standard panel size is governed by the size of their in-house CNC cutting machine, rather than the casting bed. For the Prada Museum, Fondazione Prada, in Milan designed by OMA (2015) CYMAT manufactured 6 × 3m panels.

The stabilised foamed aluminium cladding of the Mallorca Congress Centre is 12.7mm thick. The panels are mechanically fixed to a substrate of aluminium extrusions, sitting in front of the breather membrane, insulation and structural steel work. The panels form fin-like solar shading, which are visually comparative to stone yet extremely light in weight.

Having undertaken subsequent wind load tests, CYMAT offer panels that can be fixed using a two-part acrylic adhesive (3M's DP 810NS) on facades up to eight storeys. Exova Canada in 2013 undertook load testing to ASTM E330 – 2010 (Procedure A) on 2440mm × 1220mm, 43.3mm thick panels of stabilised foamed aluminium.[55] This assembly was tested to a load of 1000pa, equivalent to 90mph wind, with a deflection of 4.1mm to 4.6mm for wind pressure and wind suction respectively. The panels experienced cohesive failure at 3500pa. Exova UK undertook independent testing of aluminium finishes, included in TSC Book One *Aluminium and Durability*.[56]

Francisco Mangado believes that 'on the one hand, the project design aims to make the most of the light of Palma generating a series reflections and defined shadows, and, on the other, it plays with the image of a large beached fish, of well-defined forms and geometries'.[57]

Fig 6.51 Mallorca Congress Centre, Palma de Mallorca, Spain, architect Francisco Mangado, 2008

Anibal Building, Ipanema, Rio de Janeiro, Brazil: Architect Bernardes Arquitetura, 2015

A family firm commissioned Architect Bernardes Arquitetura to design this office building for the coastal neighbourhood of Rio de Janeiro, Ipanema, in part for their own use. The brief called for a high-quality office that was both attractive and discrete. The climate of Rio de Janeiro, based on the Köppen-Geiger climate classification system, is tropical savannah (Aw), but in close proximity to a tropical monsoon climate (Am). Therefore, solar shading is a major factor in the design of a new office building within this climate.

This four-storey office building, completed in 2015, replaces an earlier residential building on the site. 'Project architect Francisco Abreu explains the practice's approach: "Planning regulations meant we could not go any higher than the previous building."' [58] A key design issue was to achieve very good daylight, yet avoiding overheating. This was achieved by introducing a modest atrium to the rear of the block, lit via 10m^2 rooflight. Useable space is maintained on each floor by introducing clear glass flooring within the atrium, comprising 40mm toughened and laminated glass. The street elevation is also fully glazed to maximise daylight. This is veiled externally by a diagrid of perforated aluminium solar shading. Technosystem of São Paulo fabricated the 10.7m x 11.5m field of solar shading in perforated aluminium. Although bespoke, this solar shading is fabricated from standard aluminium sheets that are 4m long, 150mm wide, and 5mm thick with circular perforations. It took six weeks to install. The solar shading is polyester powder coated white.

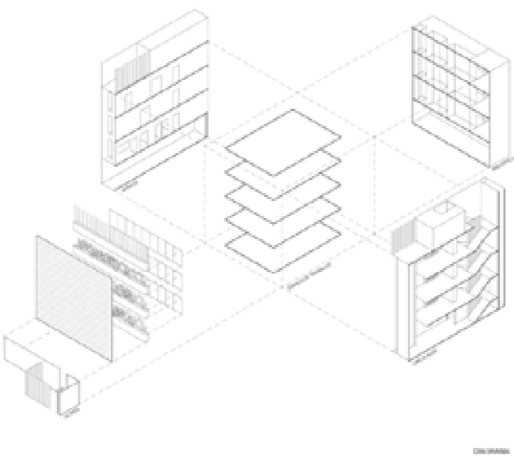


Fig 6.52 Elemental axonometric of the Anibal Building, architect Bernardes Arquitetura, 2015

Fig 6.53 Anibal Building, architect Bernardes Arquitetura, 2015

Fig 6.54 Facade detail of the Anibal Building, architect Bernardes Arquitetura, 2015

The architect observed that all of the components 'are salt resistant as the ocean is just a couple of blocks away.'[59] The building delights the client and the tenants find the building a pleasant environment to work in.

Fig 6.55 The library slot or atrium of the Anibal Building, architect Bernardes Arquitetura, 2015

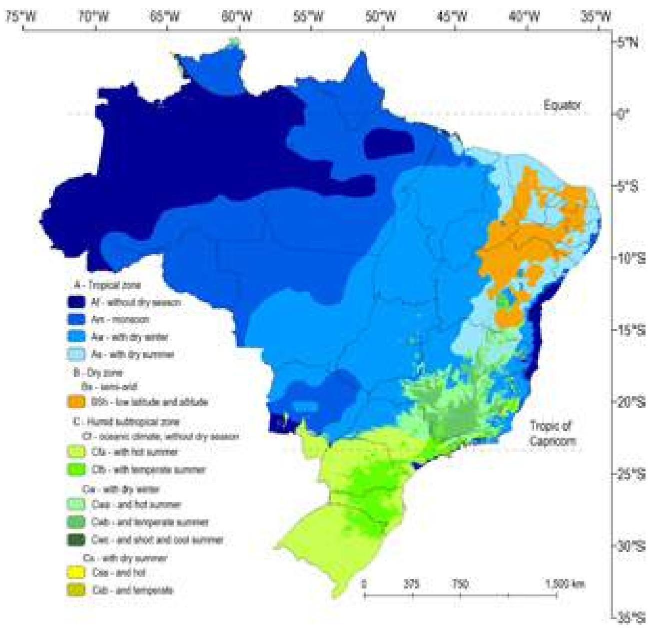


Fig 6.56 The view out through the aluminium perforated louvers of the Anibal Building, architect Bernardes Arquitetura, 2015

Fig 6.57 Köppen-Geiger climate map of Brazil

Fig 6.58 Anibal Building, architect Bernardes Arquitetura, 2015

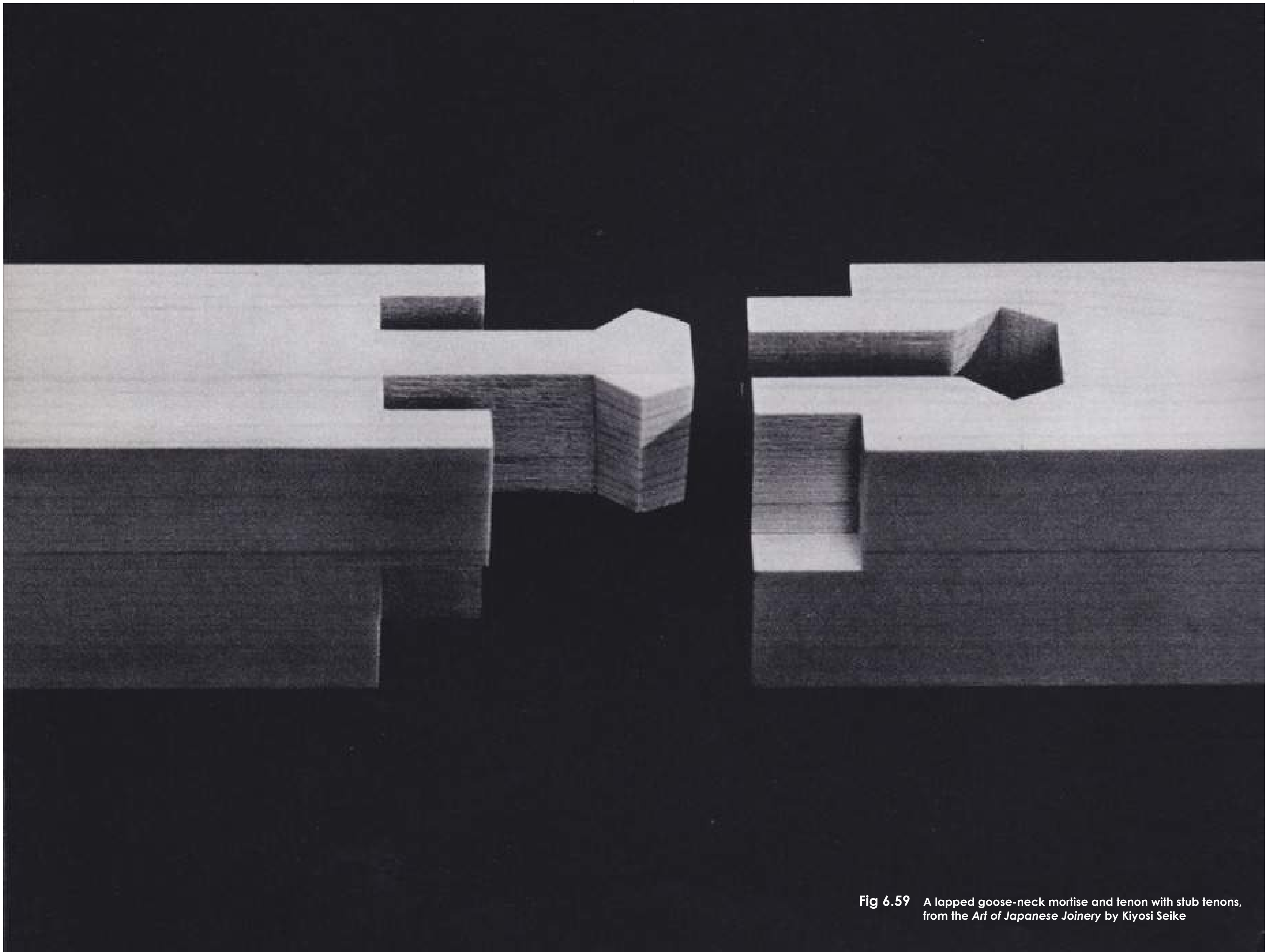


Fig 6.59 **A lapped goose-neck mortise and tenon with stub tenons, from the *Art of Japanese Joinery* by Kiyosi Seike**

Qianmen East, Beijing China,
Architect Kengo Kuma & Associates, 2016

Qianmen East is a district in central Beijing, which is only five-minute walk from Tiananmen Square. It is a historic area, which largely comprises classical Qing and Ming Dynasty courtyard houses, know as Siheyuans arranged along alleys or Hutongs. Kengo Kuma & Associates (KKA), who were asked to renovate this area, observe that with the explosive growth of the population in big cites like Beijing, 'these houses began to be occupied by people who were strangers to each other. As a result, the historic Siheyuan (courtyard houses) became slums, and were even called Da-zayuan (messy houses).' [60]

KKA sought to reinvigorate the district with a mixed-use programme, including offices, shops, restaurants, hotels and housing, whilst retaining and refurbishing the existing building stock of courtyard houses. Forming part of this overall project for Qianmen East KKA converted a courtyard house into a café and offices for the practice in Bejing. The wooden structure of the courtyard house has been dismantled, repaired and reassembled by local carpenters. The new walls are a combination of brick and curtain walling, which is shaded by a screen of interlocking anodised aluminium extrusions. KKA have opened the courtyard to the street via controlled transparency. The screen is simply formed using two interlocking aluminium extrusions, cut sectionally to reveal the form of the extrusion - a direct result of the die. Extrusion is one of the most direct means of translating a drawing into a building component, and preceded rapid prototyping and three-dimensional digital printing. The two extrusions create an organic pattern, formed like a jigsaw puzzle, generating a pattern that can be considered part of the Chinese lattice pattern tradition known as Huagechuang, which is often applied to windows and doors.

The aluminium screens are hung from brackets, which attach to the reverse of the screens at the top to an internal timber beam that has been added to the existing structure and left exposed. On large areas of the screens, an additional bracket ties it back to the glazing mullion. A base pin connection is concealed within the zone of brick and stone paving. Within the courtyard, a canopy made from the same anodised aluminium extrusions signals the entrance. The overall aim of the project for KKA is to demonstrate that the Hutongs and Sheyiuans do not need to be demolished and replaced by high-rise buildings, by proposing the revitalisation of these traditional typologies with new programmes of use and inventive tectonic strategies.[61]

At Fabricate 2017, in Stuttgart, [62] Kengo Kuma explained how Qianmen East is part of the body of work by his practice that started

Fig 6.60 Qianmen East, Beijing,China, architect Kengo Kuma & Associates, 2016

Fig 6.61 The interlocking anodised aluminium extrusions of the screens of Qianmen East, Beijing,China, architect Kengo Kuma & Associates, 2016

with experiments, often conducted with architecture students, researching the art of Japanese joinery, as delightfully described by Kiyosi Seike in his seminal book Kigumi.[63] An example of this is the interlocking timber structure of the Cidori pavilion (2007), which uses no fixings or adhesive and is this readily assembled and dissembled - a poetic example of design for disassembly (DfD). The Yusuhara Wooden Bridge Museum (2010) uses a development of these traditional timber techniques to produce a cantilevered bridge structure from repeated laminated timber elements. This series includes investigations of aluminium extrusions, which are used in a similar manner to Polygonium (2008) and comprise a card-like structure of trusses, which serve as a shelving system. This reconfigurable system is made up of six aluminium extrusions – the shelf/cord unit is a single extrusion with a very narrow long central slot and five solid aluminium extrusions that join these extrusions from pairs of extrusions to polygonal arrangement of six cord extrusions, hence the name Polygonium.

The inventive solar shading of Qianmen East is a result of historic cross cutting cultural currents and cultural dialogue between China and Japan reimagined by Kengo Kuma. This inventive solar shading, comprising interlocking bespoke anodised aluminium extrusions, is inspired by the art of Japanese joinery - a living tradition in Japan that arrived just like Buddhism from China.[64]

Fig 6.62 Qianmen East, Beijing,China, architect Kengo Kuma & Associates, 2016

Tinhouse, Isle of Skye, Scotland: Architect Rural Design, 2016

The Tinhouse is an aluminium-clad house designed by architect Rural Design led by Alan Dickson and Gill Smith set in the delightful rural landscape of the Isle of Skye, part of the archipelago of islands forming the western seaboard of Scotland. The house is located on the north-western tip of the isle, on a steeply sloping site over looking the Minch, the strait of water that separates the Inner and Outer Hebrides. The site is often battered by sea storms. The form and cladding of the house is inspired by simple agricultural buildings clad in corrugated metal. The roof and walls are clad in mill finish aluminium, which will slowly patinate to a soft grey. The house was self built, predominantly by Alan Dickson, and therefore the light weight of the aluminium sheeting was important, as it can be easily handled by one person. The sinusoidal corrugations run vertically on the walls and continue up and over the roof. The sheeting was roll formed by Rigidal Aluminium. All flashings and window surrounds are formed from flat mill finish aluminium sheeting. The thermally broken double-glazed windows are silver anodised with 25µ to BS 3987:1991 and were fabricated by Rationel. On the north and west elevation, the windows form a long low slot, which captures the views of the Minch. This run includes three outward opening windows. A painted yellow opaque panel within this run of windows signals the presence of the kitchen. This is the only splash of colour on the exterior facade and is echoed on the lobby wall of the entrance, which can be closed off by a horizontal sliding solid timber door.

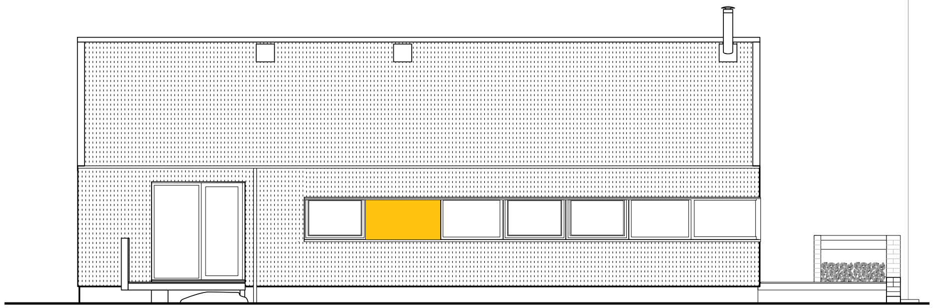
Fig 6.63 Tin House, Isle of Skye, Scotland, architect, Rural Design, 2016

Fig 6.64 Tin House, Isle of Skye, Scotland, architect, Rural Design, 2016

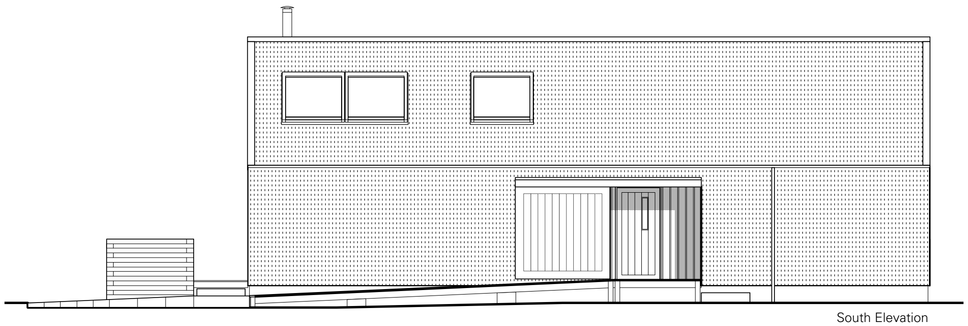
The house was built over a three-year period and Alan Dickson estimates that it took some 400days to build,[65] saving an estimated £50,000, meaning this 70m^2 house only cost £110,000. The plan is direct and effective, comprising a kitchen-living room, with a bathroom core behind the kitchen and a single bedroom that completes the rectilinear plan. The south side of the plan, which snuggles up to the hillside, comprises a run of cupboards for much needed storage. Internally the material palette includes an exposed concrete floor, white painted timber lining and plywood joinery. The interior uses 'moments' of colour inspired by the island landscape from a wildflower-yellow to a sky-blue.[66] The house is currently let as a holiday home to 'help smooth out the financial ups and downs of running an architectural practice in one of the most remote parts of Scotland'.[67]

Fig 6.65 The living space of the Tin House on the Isle of Skye is defined by the expansive landscape and not the building envelope

Fig 6.66 The mill-finished aluminium cladding of the Tin House, Isle of Skye, Scotland, architect, Rural Design, 2016

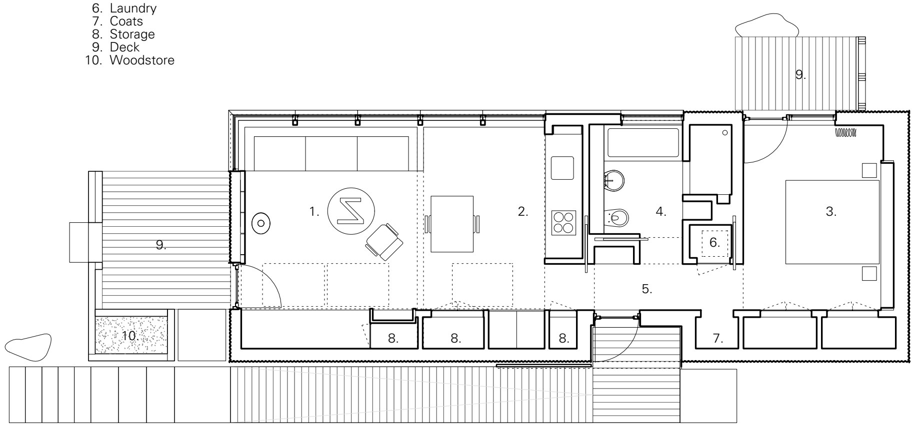


North Elevation

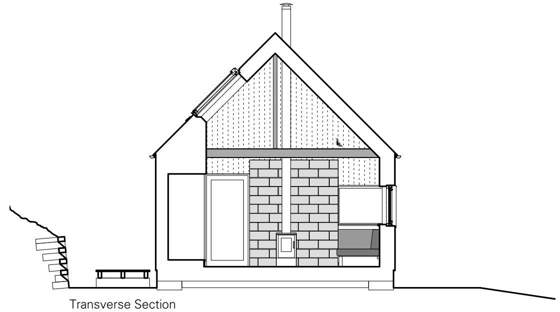


South Elevation

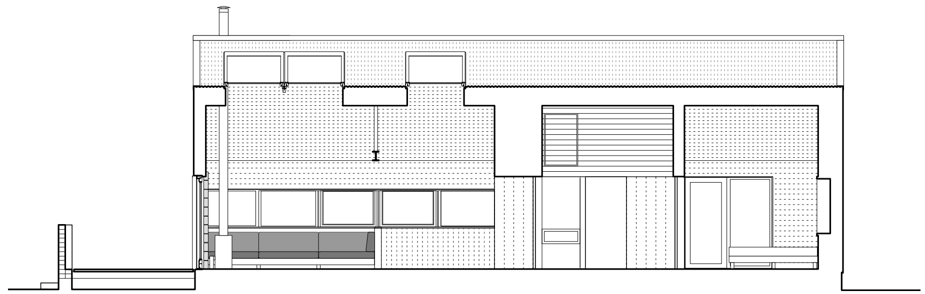
1. Living / Sitting
2. Kitchen / Dining
3. Bedroom
4. Bathroom / Shower
5. Entrance
6. Laundry
7. Coats
8. Storage
9. Deck
10. Woodstore



Ground Floor Plan



Transverse Section



Longitudinal Section

Fig 6.67 Rural Design's elevations, plan and sections of the Tin House

Rural Design consider the house ‘to be an essay in landscape, economy, construction and imagination’. The careful placement of this aluminium-clad house in a picturesque landscape demonstrates that aluminium can be used sympathetically and powerfully in a rural context.

Fig 6.68 Tin House, Isle of Skye, Scotland, architect, Rural Design, 2016

Sawmill Shelter, Hooke Park, England: Designed and Built by AA Design + Make Students, 2016

This is another example of self-build architecture, where the lightweight qualities of aluminium cladding combined with its inherent formability result in its selection for its rural context, a woodland at Hooke Park, in the English county of Dorset. This 140hectare woodland is owned and run by the Architectural Association (AA). The canopy structure provides shelter for a sawmill and its operator, whom process timber for the AA students to use in their design and build projects – a modest yet highly purposeful example of rural industrial architecture. The new canopy shelters an existing 10m x 5m concrete slab. Martin Self, AA Director of Hooke Park, observes the Sawmill Shelter provides 'a test-bed for the experimental prototyping of structural systems that will be deployed in the next planned construction at Hooke Park, a lecture hall and library that will form the academic centre of the campus.'[68] The shelter took inspiration from the first building at Hooke Park designed by Frei Otto with Ahrends, Burton & Koralek (ABK Architects), completed in 1987.

Students can select species of tree and specific trees from the woodland with the advice of forester Christopher Sadd. This is, in essence, an ancient building craft, yet both the design and fabrication are undertaken using state of the art digital design and computer-controlled machinery.

The experimental tensile-timber canopy, which is weather proofed by an aluminium skin, was designed and built by students of the Architectural Association's Design + Make MArch course. The timber of the roof is primarily in tension. The canopy structure has been designed to resist both snow loads and wind uplift. Martin Self describes the structure:

> The timber net spans about 11m and is formed from 38 × 38mm laths of western red cedar sourced from an adjacent stand of trees. To remove imperfections, the laths were assembled from shorter sections using a glued finger-jointed scarfed splice that was developed and tested at Hooke Park. Each lath carries up to two tonnes of tension, demonstrating the remarkable – and generally underexploited – strength of wood under tension.

One side of the canopy is supported by steam bent and laminated timber, cut from complete tree trunks. Student En-Kai Kuo led this aspect of the canopy structure. Another student observed: 'This project began in July 2016 with the premise that it would be a full-scale structural and visual prototype for the future canopy roof structure over the Wakeford Hall building complex.'[69]

Fig 6.69 Sawmill Shelter, Hooke Park, England, designed and built by AA Design + Make Students, 2016

Fig 6.70 **Sawmill Shelter, Hooke Park, England, designed and built by AA Design + Make Students, 2016**

The timber structure is skinned with 6mm plywood to a digitally unfolded tessellated geometry cut on a CNC router. This is waterproofed using 0.9mm mill finish aluminium alloy, 1050A H14. Over time this will mellow to a soft grey via patination forming a stable aluminium oxide coating. Aluminium was selected as it offered cost effective durability and the students in the Hooke Park workshop could readily work it. They cut and folded the panels, gutters and downspouts. The panels were lapped down the anticlastic curve of the canopy, secured with double sided exterior fixing tape and riveted into place. The gutters and downpipes are also riveted at frequent centres, making this aspect of the canopy reminiscent of 1930s aluminium aircraft technology - before the flush rivet had been invented. The aluminium skin reflects the sky and woodland, and compliments the timber structure of this sawmill shelter.

Fig 6.71 Sawmill Shelter, Hooke Park, England, designed and built by AA Design + Make Students, 2016

Optic Cloak, Greenwich Peninsula, London England: Artist Conrad Shawcross with Architect CF Møller, 2016

Chapter Three of TSC Book Three *Aluminium Recyclability and Recycling* examines Greenwich Peninsula as a zone of change - starting in 1851, the year of the Great Exhibition housed in the Crystal Palace design by Joseph Paxton, to the present day – then 2015.[70] This chapter, which illustrates how cities change, contains Allies & Morrison's new masterplan for the peninsula, prepared on behalf of Knight Dragon Development Ltd. The masterplan takes the number of new homes on the peninsula to over 15,000. The construction of these new homes continues at a pace. To serve these new homes and reduce their collective carbon footprint, Knight Dragon with Pinnacle Power commissioned CF Møller to design an Energy Centre - a combined heat and power plant.

The Energy Centre is prominently located at the western edge of the peninsula next to the busy Blackwell Tunnel approach road. The flue tower, which is almost 50meters tall, houses ten chimneys and a maintenance access staircase. Rather than leave these elements exposed or simply clad like the base of the building, CF Møller collaborated with British artist Conrad Shawcross, who designed a perforated aluminium cladding – Optic Cloak. Shawcross considers Optic Cloak to be an architectural intervention rather than a public artwork: 'It's important to me that it isn't seen as the biggest architectural sculpture in South East London…. Instead of pretending it isn't a chimney, I hope it's a celebration of a chimney.'[71] Optic Cloak clads the chimney-stack that is 49m high, 20m wide on its East and West façades but only 3m on the North and South façades. It is oriented almost perfectly with the cardinal points of the compass. Shawcross working with engineers Structure Workshop developed a pattern of triangular panels that disrupt and animate the surfaces of the Optic Cloak. The panels are made of perforated 3mm aluminium sheet, which are finished with silver anodising. In comparison, the i360 vertical peer (2016) in Brighton designed by Marks Barfield is clad in 5mm expanded aluminium sheets.[72] Unlike the camouflage paint of a Dazzle Ship, the panels are consistent in their silver or natural anodised colour, but the sub frame holds them in an origami-like set of folds. This generates a diversity of planes that respond to the ambient light. The triangular panels on Optic Cloak range in size up to 7m long, but are subdivided to allow the developed panel (final panel size) to be made from 4 x 2m sheets of perforated aluminium.[73] The cladding was installed by Lakesmere, whose many projects include the aluminium standing seam roof of the London 2012 Olympic Aquatic Centre designed by Zaha Hadid Architects.

Fig 6.72 Optical Cloak, Greenwich Peninsula, London, England, dawn to sunrise 25 May 2017, at 5minute intervals

Shawcross has achieved a wide range of optical effects, primarily based on the east west orientation of the tower and the way each panel catches the sunshine. Figure 6.68 shows the tower on 26 May 2017 from before sunrise to an hour later and then full sunshine. From the Peninsula Park, the westerly setting sun reveals the perforations in the aluminium panels. In certain light, or perhaps the uncertain light of a grey English day, the panels of aluminium look descriptively like glass.

In the twenty-first century aluminium components are helping to assemble buildings of the highest quality yet at affordable cost, whilst providing long term durability, reusability and if necessary almost infinite recyclability.

Fig 6.73 Optical Cloak, Greenwich Peninsula, London, England

Fig 6.74 Optical Cloak, Greenwich Peninsula, viewed across the cars queuing for the Blackwall Tunnel

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Fig 6.75 Aluminium solar shading of the Grade 1 listed – St Catherine's College, Oxford, England, architect Arne Jacobson, 1964, photographed in 2016

aluminium: sympathetic and powerful

weston library

Weston Library: reinventing a Bodleian Library, Oxford

In the heart of Oxford's historic centre is Bodleian Library, which opened in 1602, yet owes its origins to the University of Oxford's first library, founded in circa 1320.[1] Alongside the British Library, Bodleian Library is one of six legal deposit libraries in the United Kingdom and Ireland, a role undertaken by the Library of Congress in the USA. In the 1930s the Bodleian Library was reaching full capacity, with one million books in the library by 1914, the Bodleian Library observed 'in 1931 the decision was taken to build a new library, with space for five million books, library departments and reading rooms, on a site occupied by a row of old timber houses on the north side of Broad Street.' Sir Giles Gilbert Scott was commissioned to design a new building in 1934.[2] The Rockefeller Foundation provided three-fifths of the cost of the new library, with the balance provided by the university.[3] The New Bodleian Library was constructed on a spacious site to the north of Bodleian Library between 1936 and 1940, by Benfield & Loxley, at a cost of £379,300.[4] It is a steel framed building clad in English Limestone with anodised aluminium windows. Used primarily as a book repository, Sir Giles Gilbert Scott's design for the New Bodleian Library, although clearly a civic work of architecture, was not a very public building. Scott's massing of the building respects the Carfax guideline, which limits the height of buildings within 1.2km of the 23m-tall Carfax tower to 18.2m (approximately four storeys). Thus, three basement floors were required for bookstacks.[5]

Fig 7.1 The Weston Library, Oxford, England, photogrphed in 2016

Fig 7.2–7.3 Crowds gather for the opening of the New Bodleian Library by King George VI i on 24 October 1946, from above and at the main door to the library

The building first saw service during World War Two under the control of British Naval Intelligence. It opened in August 1940 to mixed reviews from J. M. Richards (under the pseudonym James MacQueady) and Nikolaus Pevsner.[6] Sir Giles Gilbert Scott's

design is an example of stripped Classicism, built using highly contemporary construction methods. Pevsner suggests: 'It's not neo-Georgian by any means, yet it seems undecided how far the safe anchorage in history might be loosened [with] Georgian window proportions'.[7] The library was, however, Grade II listed on 1 September 2003 by Historic England (formerly English Heritage).[8] This listing recognises the high quality of Gilbert Scott's design and the careful selection of materials throughout the library, recording the use of aluminium alloy windows, but with no reference to the finish.[9] In 2008 Toby Kirtley, estates project officer for Oxford University Library Services, observed how reliable these windows had proved in over 70 years of use.[10] King George VI formally opened the library as the New Bodleian Library on 24 October 1946.[11]

Fig 7.4 The New Bodleian Library, Oxford, England, photographed in the summer of 1940

Reinventing the New Bodleian Library

The starting point for the refurbishment and reinvention of the New Bodleian Library was to reduce the risk of the book repository being destroyed by a fire. A 1998 fire safety report, commissioned by Arup, reported 'a one in three chance of the whole building burning down if there was a fire'.[12] The environmental conditions in which the books were stored also needed updating. The storage capacity of the New Bodleian Library was relieved by the construction of a semi-automated high-bay storage facility in Swindon in 2010, with a capacity of nine million books.[13] This enabled the library to be reinvented as a place for interdisciplinary research and public engagement, with a clear focus on physical artefacts such as a Tudor map or a medieval manuscript. The library reopened to academics in October 2014 and the public in March 2015 as the Weston Library, named in honour of the £25million donation given in March 2008 by the Garfield Weston Foundation. The Weston Library now houses just over 1.25million volumes,[14] in closely controlled environmental conditions.

Fig 7.5 The Weston Library, Oxford, England, photographed in the summer of 2016

In summer 2006, WilkinsonEyre were one of six architectural practices invited to enter a competition to redesign the New Bodleian Library. WilkinsonEyre won with a clear strategic approach, clear spatial ideas and a strong understanding of the architectural context of the existing library. They realised the project would require close collaboration with the client and the

Fig 7.6 The Foyer and events space of the Weston Library, Oxford, England,

diverse users of the library. Geoff Turner observed: 'Not only did we need to address the conflicting and overlapping requirements of archival storage, academic and interdisciplinary research, but we also had to deal with a far broader brief for public engagement and exhibitions.'[15] During the competition WilkinsonEyre realised that the Bodleian's librarian, Richard Ovenden, and Toby Kirtley, estates projects officer, were open to the written brief being challenged and developed.[16]

WilkinsonEyre's project statement, written by Jim Eyre as part of the detailed planning application, observes of the New Bodleian Library that: 'The existing building is in one of the most historically sensitive parts of the city, and is part of a series of buildings forming one of the most memorable urban "set pieces" in the United Kingdom.'[17] Jim Eyre realised: 'While acknowledging that the core purpose of the project was of course upgrading of its book storage and the creation of a special collections research library with facilities for public engagement, it was nevertheless the physical context of the building that generated inspiration for our design –

and with it the idea of opening up the southern elevation at the ground floor level.'[18] Thus, providing the library with a significantly improved and fully accessible entrance sequence. The south façade of the library faces across Broad Street onto Nicholas Hawksmoor's Clarendon Building (1715) and Sir Christopher Wren's Sheldon Theatre (1669), which was the first Neoclassical building in Oxford and contains reference to Palladio.[19] Wren was only 31years old when he designed this theatre. Sir Giles Gilbert Scott's design was respectful of the building line on Broad Street, and deferential

Fig 7.7 The Weston Library, Oxford, England, photogrphed in 2016

to the Neoclassical antecedents, which includes buildings by Nicholas Hawksmoor, Sir Christopher Wren and James Gibbs, yet did not engage with its context as it has a plinth to the southern façade and it's entrance on the western elevation of Parks Road. Scott composes the libraries' elevations from anodised aluminium windows with Bladon limestone as rubble coursing and Clipsham limestone for dressed details.[20] This material palette gives a light-honey tone to the elevations, compared to the warm-honey tone of the Clarendon Building, originally constructed from Headington

Fig 7.8 The Radcliffe Camera, Oxford, James Giggs, 1749, the best example of Baroque architecture in Britain

freestone and repaired in 1909 using Clipsham limestone.[21] All are limestones with the Bladon being sourced in Oxfordshire. Alex Clifton-Taylor observes that Oxford 'uses some of the most rewarding building stones in England'.[22] In 1978 the author visited Oxford with Jim Eyre, as first year architecture students from the

Fig 7.9 The context of Weston Library Broad Street, Oxford, England, photogrphed in 2016 – it looks like the wrong detectives are in town

University of Liverpool School of Architecture, on a field trip lead by the architectural historian Quentin Hughes, which included a visit to the Bodleian Libraries.[23]

Major surgery was required to in order to make the library fit for purpose in the twentieth-first century, WilkinsonEyre organised a major internal refurbishment of the eleven floors of the library, three of which are under ground. The removal the bookstacks enable the library, in Jim Eyre's imagination, to have a public quadrangle at its core, a common figure ground for Oxford. This public quad creates the opportunity for the library to form part of a sequence of such spaces in the core of Oxford. As the design developed the new quad became Blackwell Hall, a ground floor entrance and events space incorporating a café. To maintain book storage capacity, a floating bookstack was designed as a 22m clear span concrete Vierendeel truss structure, which spans between two new concrete cores and over sails Blackwell Hall with a tapering atria on the south and north sides. WilkinsonEyre were keen for these spaces not to appear or feel like a shopping mall or corporate atria, more a gentle modulator of daylight, with discreet views into the bookstacks. Three floors of basement archival bookstacks have also been retained, with fire safety and environmental improvements.

Early in the design process, WilkinsonEyre 'made a research trip with Richard Ovenden and the project team to look at particular libraries in the United States, just as Scott did with his clients of the

Fig 7.10 The collection of the Weston Library, a Bodleian Library, Oxford, is both extensive and inclusive, from local heroes to Islamic texts

original library.'[24] This highlights the continued value of using field research to inform design quality of a project, whether it be during the 1930s or 2000s. A key precedent for the design of Blackwell Hall was Gordon Bunshaft's 'magical temple to knowledge – Yale's Beinecke Library.'[25] Here, Bunshaft places the 'bookstacks in a glazed box within a building whose outer rectilinear shell of concrete and translucent stone controls light levels and imbues a sense of awe.'[26] Blackwell Hall has a cloister-like glazed first floor gallery, which makes both books and readers visible, whilst animating the public realm of the library, maintaining security and permitting close climatic control. Map librarian Nick Millea believes: 'The building is stunning now. It was dark and gloomy before, like an old station. It was intimidating to visitors. For me, the thing that delights me every time is when you pass one of the viewing areas into the old bookstack.'[27]

Tim Abrahams observes, WilkinsonEyre 'has not only addressed some of the problems of the old building but made them into virtues. It has converted the blank south-facing façade into a recessed arcade, and re-formed the plinth the building was inexplicably placed on into shallow steps. Both measures help turn the building from a closed structure into a very civic space.'[28] The Weston Library has become a highly visitable building and its ground floor, the Blackwell Hall, and atrium are part of the public realm in the centre of Oxford. One young Oxford academic in summer 2016 observed to his partner and family what a gift the new Weston Library is to the city, when compared to the New Bodleian in it's original form.[29]

WilkinsonEyre has retained all the major features of Sir Giles Gilbert Scott's original architecture, including the anodised aluminium windows. Although the library looks substantially unchanged after this £80 million reinvention, the construction waste and recycling streams of this project were substantial:

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

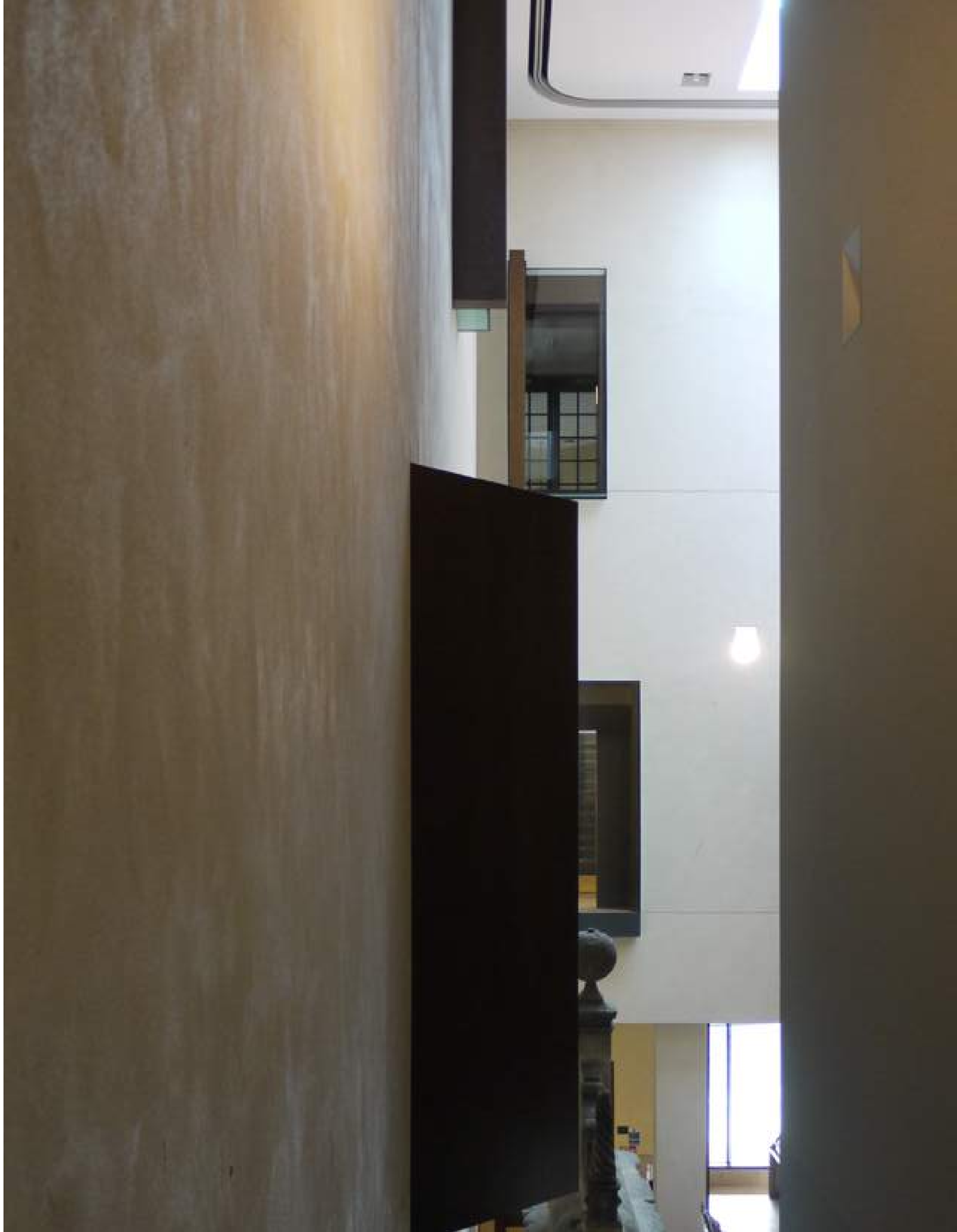

Fig 7.11 The slot-like arium on the north side of Blackwell Hall, photogrphed in 2016

This took over 170,000 worker hours during a period of 12 months.[30]

Following WilkinsonEyre's remodelling of the library, the major visible changes are the removal of the ground floor plinth, the opening of windows, which had high cills, to form a colonnaded entrance on the south façade, and removal of the Indian Institute Library, which was added between '1966-68 to the designs of Robert Potter.'[31] WilkinsonEyre had to make the design case for these changes to key stakeholders, including Historic England and the Twentieth Century Society. Jim Eyre described the presence of the Indian Institute Library by paraphrasing a famous remark 'one could say that this addition was a monstrous carbuncle on the face of a passing acquaintance. Its shortcomings were easily identifiable: the concealment of Scott's trademark vertical slot windows to the bookstacks, especially when viewed from the windows of the iconic reading room in Duke Humfrey's Library.'[32]

Where the Indian Institute Library once was, is now an accessible roof terrace that can be used for events, drink receptions of exhibition openings, and even weddings. Here the visitor is literally within the dreaming spires of Oxford, a term coined by the poet Mathew Arnold.[33]

James Timberlake, when visiting the Weston Library with the author in autumn 2106, observed how skilful Sir Giles Gilbert Scott's control of proportions was - from the aluminium window panes to the overall massing of the building. However, he also observed that Gilbert Scott's selection of classical motifs on the building was very eclectic. It would appear that there is veracity on this matter in the original criticism of the completed project, from Nikolas Pevsner and J. M. Richards in 1940.

Geoff Turner, associate director at WilkinsonEyre, reflected on the responsibility of working on a project that Scott considered an example of Gesamtkunstwerk:

> The attention to detail in Scott's design, which he envisioned as a complete work of art, meant that he not only managed the selection of materials such as stone, aluminium, bronze, steel plaster and timber, but also designed door handles, furniture and light fittings, reading tables and chairs. As architects of the renewed building we were responsible for retaining the coherence of Scott's vision, extending the palette of materials to ensure that the contemporary detailing would sit comfortably alongside, and complement, the old.[34]

Gilbert Scott used anodised aluminium windows throughout the library – a prominent architectural detail. The windows have, in essence, only been cleaned and re-glazed as part of this project. The windows were fabricated and anodised by James Gibbons, probably in 1938, and installed during 1939. Sir Giles Gilbert Scott had used the same specification for the windows as at the University of Cambridge Library (1934), which is reviewed in TSC Book One *Aluminium and Durability*.[35] James Gibbons of Wolverhampton also manufactured these aluminium windows and they are the oldest extant anodised aluminium windows in the world.[36]

Fig 7.12 James Timberlake testing out a reading cowl in the Weston Library, during the Fall – Autumn of 2016

The University of Oxford facilitated by WilkinsonEyre and Mace kindly granted the TSC research team access to the anodised aluminium windows of the library for non-destructive testing during autumn 2013.[37] This testing was undertaken by Geoffrey Addicott of independent testing organisation – Exova, with the assistance of Michael Stacey Architects. Exova's full test report can be found in Appendix A of TSC Book One *Aluminium and Durability*.[38] It is important to remember that these anodised aluminium windows of the New Bodleian Library, were 75 years old when inspected and tested. Windows from all four elevations were tested – 12 in total. Silver anodising was found to be present and the range of film thickness was very wide from 30μm to 7.4μm. Even on the internal side of the reference window, the anodising ranged from 16.5μm to 11μm; arguably, this is representative of the range of anodising thickness achieved in the 1930s. When James Gibbons of Wolverhampton organised the anodising of these windows, anodising was a new technology that had only been established in the previous decade of the twentieth century.

The anodising on all except one of the aluminium windows of the New Bodleian Library would not pass the coating thickness standard required by BS EN ISO 7599:2010. The expenditure on the overall refurbishment of this library was over £80 million. Based on the durability of the anodised aluminium windows, the design team decided that the anodised windows are satisfactory for another 60 years or more. The windows were, in essence, only cleaned and reglazed.

It had been suggested that the windows were mill-finish aluminium; however, on inspection they proved to be silver anodised, but in need of cleaning. If left without cleaning for a long time, silver anodising will patinate to a dark grey appearance that some have assumed to be mill finish. At the time of inspection, the library was being refurbished under the design leadership of architect WilkinsonEyre and the contractor was MACE. Some windows had been removed and stored to facilitate access to the interior or to allow the spatial reconfiguration of the new entrance to the south facade. On inspection the windows were single glazed with solid aluminium sections and generally appeared to be in very good condition, confirming the earlier report from the University of Oxford's estates team. The anodised aluminium windows appeared to be the only use of aluminium in the construction of this building.

The non destructive testing of the anodised aluminium windows of the Weston Library was undertaken alongside the testing of the polyester powder coated cladding system of Herman Miller Chippenham (1983) by Nicholas Grimshaw and Partners and the bronze anodised curtain walling of I Finsbury Avenue (1985) by Arup Associates. The results of this testing, including the anodised aluminium windows of the Weston Libarry, are set out in TSC Book One *Aluminium and Durability* and in the form a peer reviewed paper by M. Stacey and C. Bayliss, *Aluminium and Durability: reviewed by inspection and testing*.[39]

Tim Abrahams considers that 'it is the lovingly restoration of Sir Giles Gilbert Scott's Library's interiors that is the scheme's greatest virtue'.[40] Noting the retained and cleaned aluminium windows are a vital set of components of these interiors, which they flood with daylight and views. Jim Eyre during an interview after the Towards Sustainable Cities Symposium at The Royal Botanical Gardens at Kew stated:

> Aluminium is an exceptional material because of its shear versatility. Used carefully, it can achieve a feeling of lightness, which is a form of power in itself. Not used carefully, it can be very heavy and appear heavier

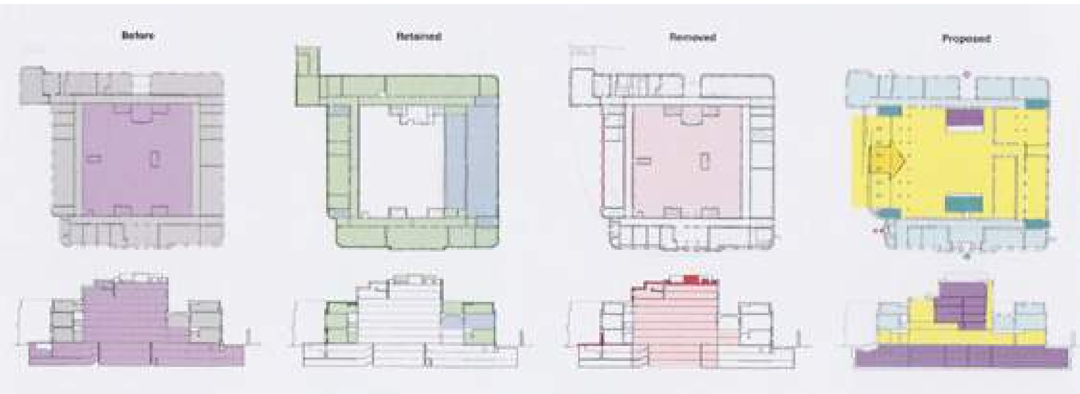

Fig 7.13 WilkinsonEyre's before and proposed plans and sections of the Weston Library

Fig 7.14 James Timberlake checking out the proportioning systems used by Sir Giles Gilbert Scott. James is bridging the gap between imperial measurement (feet and inches) he uses on a day-to-day basis in the USA and was used by Giles and the metric of modern Europe with a hand span and an iPhone

> than steel! Using it for windows on the Bodleian Library is something you need to know about, to know its aluminium because otherwise they just look like rather slender windows.

His full interview is recorded in Chapter Six, pages 118–121.

WilkinsonEyre with specialist advice undertook trials on a couple of windows that were no longer required to establish the best cleaning and refurbishment techniques. This showed that the anodising was in good condition and only a non-abrasive and neutral alkali clean was required.[41] The ground and first floor windows had anodised aluminium internal beads and were in good condition. On the second floor and above the original windows were glazed with internal putty and Geoff Turner observed this 'had degraded

badly'.[42] WilkinsonEyre replaced the putty with an anodised aluminium glazing bead, which was set back from the internal leading edge of the original T-section of the mullion and transoms to respect Scott's design aesthetic. The windows were reglazed with; 4mm clear sheet glass, 9mm Slimite gas filled double-glazing or 7mm UV barrier glass depending on the location of the windows. [43] WilkinsonEyre and the complete design team, including structural engineers Pell Frischmann and environmental engineers Hurelypalmerflatt, should be congratulated for refurbishing the library to exacting environmental standards without introducing unsightly secondary glazing. At Cambridge University Library, also

Fig 7.15 James Timberlake on the terrace of the Weston Library, Oxford – dreaming amongst the spires of academia

designed by Sir Giles Gilbert Scott, (1934) the aluminium windows now have secondary glazing, with the exception of the windows to the commons parts such as staircases.[44]

The integrated design team of the Weston Library where initially working to upgrade the library's environmental conditions, within the tight physical constraints of the existing building and in accordance with BS 5454: 2000 Guide for Storage and Exhibition of Archive Material. During the design process this British Standard was superseded by BS 5454: 2012, which incorporates the storage of digital material. The Weston Library has a BREEAM rating of Very

Good. WilkinsonEyre note that an 'Excellent rating was not possible because of the constraints of the building's heritage listing and the narrow environmental control envelopes required to achieve BS 5454 archive standards in the bookstack areas.'[45]

Following the Weston Library's formal reopening in March 2015, the reinvented library has received an excellent reception, unlike the reviews of 1940. It won a Royal Institute of British Architects 2016 National Award in recognition of the design excellence of the work by WilkinsonEyre and the sensitivity of their handling of Scott's original architecture. The Weston Library was shortlisted, as one of six projects, for the RIBA 2016 Stirling Prize, the most prestigious prize for architecture in the United Kingdom, which has a significant international reputation. Although Weston Library lost to Newport Street Gallery by Caruso St John, which is daylit via Schüco aluminium roof lights, Tim Abrahams writing in the Architects Journal Stirling Prize special edition observed that although the library was arguably not as spatially dramatic as other shortlisted projects, 'it is the building on the Stirling shortlist that will endure the longest'.[46]

Fig 7.16 The Rare Books and Manuscripts Reading Room in the Weston Library with its restored cigar box timber ceiling

Notes

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39 M. Stacey and C. Bayliss, (2015) *Aluminium and Durability: reviewed by inspection and testing*. Materials Today: Proceedings 2, pp. 5088–5095.
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Fig 7.17 Jasper Salway's drawing of the New Bodleian Library, circa 1936 – signed by Sir Giles Gilbert Scott

conclusion

Conclusion

The Towards Sustainable Cities research programme has been a remarkable journey of searching and re-searching over a five-year period. This research programme also draws on 40 years of research into materials and architecture by the author. The author's first ever paper *Aluminium Extrusions,* written with Dr Alan J. Brookes, was published in the Architects' Journal on 20 November 1985. The five books, that comprise the Towards Sustainable Cities are:

- *Aluminium and Durability* (2014);
- *Aluminium Recyclability and Recycling* (2015);
- *Aluminium and Life Cycle Thinking* (2015);
- *Aluminium: Flexible and Light* (2016);

  and this book –
- *Aluminium: Sympathetic and Powerful* (2017).

Each book benefits from focused research by a dedicated research team and a wealth of experience combined with a responsive industry that is keen to serve humankind well.

The timeline for aluminium and architecture begins with the identification of aluminium as a constituent of alumina by Sir Humphrey Davy's in 1805, and as discussed in the introduction of this book the oldest extant use of aluminium in architecture is the painted ceiling of Church of St Edmund, King and Martyr, Fenny Bentley, Derbyshire, England installed in1895.[1] Some 40 years later, the first use of aluminium in bridge building is for the replacement decks of Smithfield Street Bridge, Pittsburgh, USA, in 1933, as shown in the enclosed timelines on pages 302–305.[2] The introduction of this book also notes that aluminium is a material used again within fine art in the 1960s, after it has become an everyday material, or at least a familiar material used in industry.

On Saturday 12 December 2015 the COP 21 meeting in Paris announced a global agreement on climate change, the United Nations had spent 23 years seeking a collective agreement to tackle this issue of global significance. The full text of the UN *Framework Convention on Climate Change* can be downloaded via *unfccc.int*.[3] This global agreement on climate change is discussed further in TSC Book Four *Aluminium: Flexible and Light*. To lobby the COP 21 meeting in Paris, Michael Stacey Architects designed and published two hand-outs for the IAI – *Aluminium: Towards Sustainable Cities, quantifying the in-use benefits of aluminium in* architecture and infrastructure and *Aluminium: Benefits in Transport,* quantifying the in-use benefits of aluminium

Fig 8.1 The Five Hundred Meter Aperture Spherical Radio Telescope, Pingtang, Guizhou, China, is skinned in perforated aluminium sheeting

in all forms of transportation. The later hand-out on *Aluminium: Benefits in Transport* has also been translated into Chinese.

The tragic events of hurricane Harvey in Texas and Louisiana in summer 2017 highlights that humankind need to be vigilant and proactive in tackling climate change. Furthermore, we need to

Fig 8.2 Detail of the assmebly of The Five Hundred Meter Aperture Spherical Radio Telescope, which is clad in perforated aluminium

design and build our cities to be sustainable in the every day and during storm events. Humankind has the design skills, knowledge and technology to create sustainable urban drainage, green spaces for play and flood reserves, once called water meadows, flood resistant housing, low environmental impact architecture and walkable placement in urban districts, to name some of the issues. Well-informed design teams of architects and engineers can create sustainable urban architecture and infrastructure.

The TSC research programme has sought to generate a holistic view of the aluminium industry, including the industries it interfaces with and the socio-economic context on a global basis. Perhaps this can be considered a modest example of holistic thinking, as advocated by The Capital Institute.[4]

Need for further research

During the course of the TSC research programme, significant research gaps have been identified:

- The behaviour of aluminium in building fires, including the potential of intumescent polyester powder coating;
- Awareness;
- Education;
- Designing with aluminium, including structural performance;
- Lack of contemporary technology transfer - especially in lightweight structures;
- Fascination with robots rather than industrial processes by leading University research teams in architecture and engineering. This was clearly demonstrable at Fabricate 2017 in Stuttgart.[5]

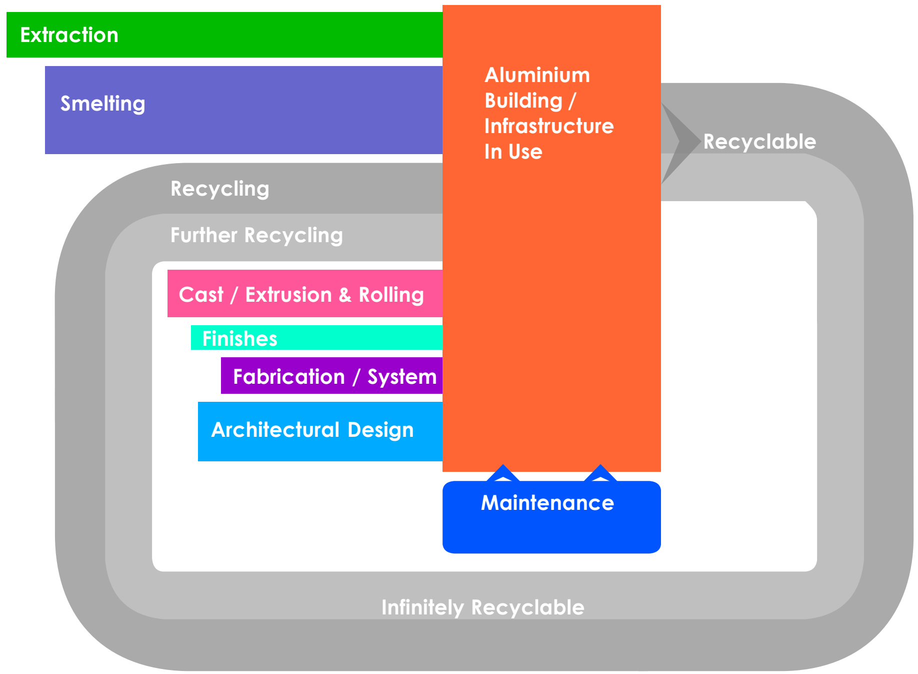


Fig 8.3 All participants In the aluminium industry add value: including the owners and managers of architecture and infrastructure via inspections and maintenance during the in-use phase

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, which is why the TSC book series begins with this topic, which is also foundational for TSC Book Three *Aluminium Life Cycle Thinking*.

TSC Book One *Aluminium and Durability* charts almost one hundred years of the use of aluminium in architecture and the built environment, based on 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. Chapter Six sets out the non-destructive testing on the finishes of aluminium building components of three exemplar buildings:

- The New Bodleian Library, Sir Giles Gilbert Scott (1940) - refurbished by WilkinsonEyre (2015);
- Herman Miller Factory, Grimshaw Architects (1983);
- 1 Finsbury Place, Arup Associates (1985). [6]

Fig 8.4 The New Bodleian Library, Sir Giles Gilbert Scott, 1940, refurbished by WilkinsonEyre, 2015

Fig 8.5 Herman Miller Distribution Centre, Grimshaw Architects, 1983

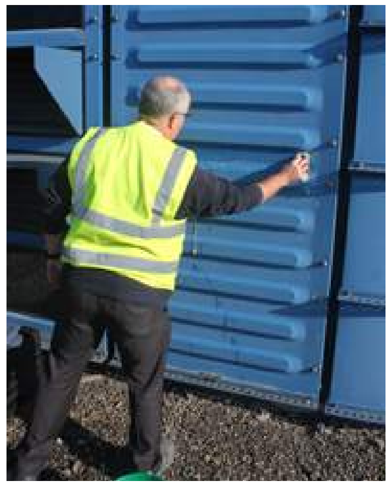


Fig 8.6 Testing the polyester powder coating at Herman Miller Distribution Centre

Fig 8.7 1 Finsbury Place, Arup Associates, 1985

The non-destructive testing was undertaken by Geoffrey Addicott of independent testing organisation – Exova, with the assistance of Michael Stacey Architects and the building owners and managers. Exova's report is published in full in Appendix A of SC Book One *Aluminium and Durability* (2014). The non-destructive testing of aluminium finishes contained within this book is also the subject of a peer reviewed paper by Chris Bayliss and Michael Stacey, *Aluminium and Durability:* reviewed by inspection and testing.[7]

TSC Book One *Aluminium and Durability* celebrates the aluminium pioneers from Raffaele Ingami via Otto Wagner to Jean Prouvé. It focuses on the key stages of the development of curtain walling, which started in the United Kingdom and France, yet came to fruition in Manhattan, New York, USA, in the 1950s via the deep

Fig 8.8–8.9 IAI COP Paris 21 hand out Aluminium: Towards Sustainable Cities, designed and produced by Michael Stacey Architects

collaboration between architects including Harrison & Abromovitz and Gordon Bunshaft of Skidmore Owings & Merrill and fabricators of this early and bespoke curtain walling. The 1950s tall buildings or skyscrapers contributed to the iconic skyline of New York, which was often experienced from the deck of an ocean linear; a visitor, a New Yorker or an immigrant all arrived in Upper New York Bay with Manhattan Island leering into view. Martin Luther King Jr. described these as the "mighty mountains of New York" in his famous speech on the Mall in Washington DC on 28 August 1963, *I had a Dream*, which conjures a future USA where all people are equal, via an eloquent evocation of the diverse landscapes of the

North American continent. Jan Morris described 'the Manhattan skyline shivered in the imagination of all the nations and people everywhere cherished the ambition, however unobtainable, of landing there one day upon that legendary foreshore'.[8] This valedictory quotation was on the front page of the New York Times on the first Sunday after 9/11, 16.9.01, following the wanton destruction by terrorists of the World Trade Centre or Twin Towers

San Gioacchino, architect Raffaele Ingami, 1897, the 1.3mm mill finished aluminium cladding of the dome of this church in Rome is performing well after nearly 120 years.

Michael Stacey

Aluminium should be recognised as a material that is very durable and when appropriately utilised and maintained provides long-term sustainability.

The anodised aluminium windows of New Bodleian Library, Oxford, architect Sir Giles Gilbert Scott, 1938 – are due to last another 60 years.

Council for Aluminium in Building

Carefully specified and tested finished aluminium is extremely durable and its functional service life is significantly longer than the associated guarantee periods.

Aluminium Centenary Pavilion was designed by Jean Prouvé in 1954, this pavilion has now been assembled in three locations: banks of the Seine in Paris, Lille and now Paris Villeprinte.

Reversible assemblies of aluminium components facilitate refinishing, relocation or recycling advancing the long-term sustainability of buildings and resource stewardship.

Dennis Gilbert / VIEW

Aluminium has an important role in reducing the demolition of existing building stock through deep retrofit, reglazing and over cladding, thus providing comfortable internal environments whilst reducing energy demand.

Commerzbank Building, Frankfurt, architect Foster + Partners, completed in 1997.

Nigel Young / Foster + Partners

Life cycle assessment is a means of modelling the embodied impacts of a material, product or building assembly. It considers the flow of materials and energy over space and time providing a quantifiable basis for decisions regarding environmental impact and performance.

A coal fired power station in Dattein, Germany.

Arnold Paul

Power mix is the most significant driver of environmental impacts of an aluminium product. Global energy mixes fail to reflect the benefits associated with the use of all fuel sources. Manufacturer and location specific data for products (EPDs) provides a truer reflection of impact.

Iwan Baan

UK Pavilion for Shanghai Expo 2010, Shanghai, designed by Heatherwick Studio, 2010.

Heatherwick Studio

A deeper understanding and use of life cycle assessment, environmental product declarations and other manufacturer-specific LCAs will enable designers to make informed material and product choices.

Barry Halkin

Loblolly House, Maryland, architect KieranTimberlake, 2006

Peter Aaron / OTTO

Aluminium has a key role in creating architecture that is affordable and comfortable, enhancing human well-being and adding value by design.

This research is quantifying 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 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.

www.s4aa.co.uk

Towards Sustainable Cities: Quantifying the In-Use Benefits of Aluminium in Architecture and the Built Environment Research Programme is funded by the IAI and undertaken by Michael Stacey Architects with KieranTimberlake.

Michael Stacey

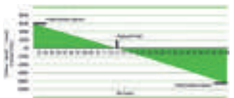
Although aluminium was a new material to architecture at the turn of the nineteenth century Otto Wagner when specifying the Postparkasse (1903) had a very clear idea of its durability, photographed in 2013.

Bronze anodised aluminium curtain walling of 1 Finsbury Avenue, architect Arup Associates, 1985. Aluminium finishes on key projects, dating from 1938 to 1985, were physically tested - all are outperforming the original guarantees.

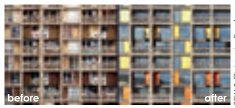
Michael Stacey

John Maltby / RIBA Collections

Aluminium is almost infinitely recyclable with no loss of material qualities. Recycling aluminium uses 95% less energy than primary production and avoids over 100million tonnes of CO_2 emissions.



Guy's Hospital Tower, London, architect Penoyre & Prasad, 2014. This anodised aluminium over cladding and reglazing of the world's tallest hospital tower has a carbon pay back period of less than 13 years.



SEW & Christophe Egret

Michael Stacey

In-use benefits: in order to accurately represent the full environmental impacts of a building product the use phase including maintenance must be included in the life cycle assessment.

Hufton+Crow

Galaxy SOHO, Beijing, designed by Zaha Hadid Architects, 2012.

Hufton+Crow

Richard Davies

Aluminium is flexible by design: it can be cast, roll formed, spun, superformed, extruded and even digitally printed, making durable components for the next generation of architecture.

Designed by Michael Stacey Architects

WORLD ALUMINIUM

www.world-aluminium.org

designed by architect Minoru Yamasaki. The Twin Towers were arguably the finest examples of architecture built in the USA during the 1970s. These inspirational and elegant skyscrapers had a column free interior and an inventive baffled aluminium rainscreen cladding.

The durability of mill-finish aluminium that has been exposed to the weather is influenced by a range of factors. This has been studied over time and in many parts of the world.[9] The starting point for the consideration of aluminium and durability is the alloy itself, in simple terms the purer the better. The introduction of other metals such as copper, to improve strength, will reduce the durability of the aluminium alloy. One option is a dual alloy with pure aluminium cold-rolled, if it is a sheet material; the second option is to anodise or powder coat the aluminium.[10]

The next step is to make certain that the proposed assembly is well detailed and the workmanship on site is of a high standard.

The benefits of aluminium use in transport go beyond lightweighting for emissions savings. It contributes to better fuel economy, enhanced performance, easier handling and reduced wear on roads. Ballingdon Bridge, Suffolk, England, designed by Michael Stacey Architects.

Reducing the weight of transportation vehicles is an important method of improving fuel efficiency – reducing energy consumption and greenhouse gas emissions. All aluminium bodied Alstom Citadis 302 Trams in Nottingham, England.

ALUMINIUM: BENEFITS IN TRANSPORT

quantifying the in-use benefits of aluminium in all forms of transportation

Fig 8.10–8.11 IAI COP Paris 21 hand out Aluminium: Benefits in Transport Cities, designed and produced by Michael Stacey Architects

Particular attention should be made to ensure the avoidance of bimetallic corrosion between dissimilar metals such as aluminium and copper. This topic has been well understood for many years, for example British Standards PD 6484; Commentary on Corrosion at Bimetallic Contacts and its Alleviation was published in 1979.

Advanced aluminium alloys are used in the wings and fuselage of Airbus A380 jetliners, Paris Air Show 2015.

master films / P.Pigeyre

The 20 million tonnes of aluminium used in transport today could save 400 million tonnes CO_2 and over 100 billion litres of crude oil over the vehicles' lives.

Cycles Devinci

Aluminium is used by Cycles Devinci to manufacture the Bixi city sharing bicycles, designed by Michel Dallaire. They are used in bicycle sharing schemes including London, New York and Montréal.

Designed by Michael Stacey Architects: www.s4aa.co.uk

A Nottingham NET Citadis 302 Tram built by Alstom in 2014, with an all aluminium body.

Michael Stacey

Aluminium is a key material, 1 kg of aluminium replacing heavier materials in a car or small truck can save a net 20 kg of CO_2 over the life of the vehicle or up to 80 kg CO_2 in trains.

Alcoa aluminium coils in Davenport, Iowa.

Alcoa

Aluminium is almost infinitely recyclable making the full life cycle cradle to cradle rather than cradle to grave. Recycled aluminium requires only 5% of the energy of primary production.

Alupro

Aluminium has many properties that make it the material of choice for application in sustainable products: durability, recyclability, flexibility, lightness and strength, high conductivity and formability.

Aluminium intensive TGV Train manufactured by Alstom.

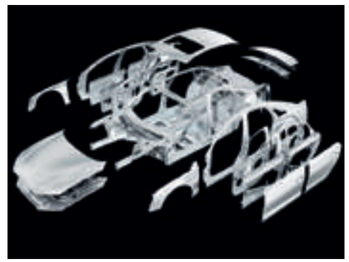
Alstom Transport / M.Spera

Over 80% of energy consumption and corresponding emissions are associated with the automotive use phase. The focus of measures to reduce energy consumption during the life cycle of a vehicle should therefore concentrate on the use stage.

Audi's Space Frame (ASF) structure consists largely of aluminium making it approximately 40 percent lighter than a comparable steel structure.

Audi

The use of aluminium in car structures allows for greater material thickness and rigidity, improving overall safety performance, and ensuring efficient crash energy absorption without adding weight. Lighter vehicles also have reduced braking distances and lower crash forces.



Audi

Lightweighting will increase intensity of use: in 2000 each automotive vehicle contained on average 100-120 kg of aluminium, in 2012 it was around 158 kg; by 2025 it is expected to be 250 kg.

Jaguar XK30 an example of the intensive use of aluminium in Jaguar Land Rover's range of fuel efficient vehicles.

Jaguar Land Rover

About 660 million tonnes of greenhouse gas could be saved during the use phase if all transport units (including road vehicles, trains and aircraft) were replaced by lightweight vehicles of current design with the same functional properties.

Novelis

A saving of approximately 870 million tonnes of greenhouse gas would be possible if existing vehicles were replaced with advanced lightweight designs.

WORLD ALUMINIUM

www.world-aluminium.org

交通用铝除了实现轻量化外，减少了车辆排放，有助于提升燃油经济性，提高性能，更易处理并降低道路磨损，以上均是公共交通系统需考虑的重要因素。
辽宁忠旺集团全铝车身客车

铝：交通运输的优势

量化铝用于所有交通运输形式的好处

降低运输车辆的重量，是提高燃料效率，降低能源消耗和温室气体排放的重要方法。
英格兰诺丁汉阿尔斯通 (Alstom) 公司的Citadis 302 全铝电车

Fig 8.12–8.13 IAI COP Paris 21 hand out Aluminium: Benefits in Transport Cities (Chinese Edition), designed and produced by Michael Stacey Architects

2015巴黎航空展 空客A380机身和机翼使用先进的铝合金

master films / P.Pigeyre

目前交通用铝达2000万吨，这些车辆使用寿命期内，减排二氧化碳4亿吨，减少原油消耗1000亿公升。

诺丁汉的Net Citadis 302电车由阿尔斯通（Alstom）公司在2014年建成，拥有全铝制车身。

Michael Stacey

铝是一种重要材料，铝替换汽车或小型卡车车身的较重材质时，在该车辆的使用寿命期内，可减排20公斤的二氧化碳，用于火车，减排二氧化碳高达80公斤。

美国铝业公司铝卷，达文波特，爱荷华州。

Alcoa

铝几乎可以无限循环使用，“从摇篮到坟墓”的生命周期扩展至“从摇篮到摇篮”。生产再生铝的能耗仅为原铝生产的5%。

Cycles Devinci

铝用于Cycles Devinci公司制造的Bixi城市共享自行车，该款自行车由米歇尔·达赖尔（Michel Dallaire）设计，用于包括伦敦，纽约和蒙特利尔的自行车共享计划，

Alupro

铝具有许多特性，使其成为可持续产品应用的首选材料：耐久性，可回收性，柔韧性，轻度和强度，高导电性和成型性。

由迈克尔·斯泰西建筑事务所（Michael Stacey Architects）设计: www.s4aa.co.uk

阿尔斯通公司生产的铝密集型TGV高速列车。

Alstom Transport / M.Spera

超过80%的能源消耗和相应排放均在汽车的使用阶段。因此，减少车辆在生命周期内的能耗措施应集中在使用阶段。

奥迪空间框架结构（ASF）大量使用金属铝，使得它比同类钢结构轻大约40%。

Audi

汽车结构使用铝增加了材料厚度和刚性，提高了整体安全性能，并且在不增加重量的前提下，确保有效吸收碰撞能量。同时，轻型车辆缩短了制动距离，并降低了碰撞力。

捷豹XK30是捷豹路虎低油耗汽车系列集约利用铝的范例。

Jaguar Land Rover

如果所有运输车辆（包括公路用车，火车和飞机）按照目前的设计，在维持相同功能特性的情况下，采用轻巧材料，可减排约6.6亿吨温室气体。

Audi

轻量化将强化使用力度：2000年各汽车整车平均包含100-120公斤铝；在2012年，大约为158公斤;到2025年，预计为250公斤。

Novelis

如果现有车辆均更换成先进的轻量设计，有可能减排约8.7亿吨温室气体。

WORLD ALUMINIUM

www.world-aluminium.org

Examples within Chapter Three *Aluminium Pioneers* TSC Book On: *Aluminium and Durability* illustrate that the need to avoid bimetallic corrosion was understood by leading architects in the 1950s.[11]

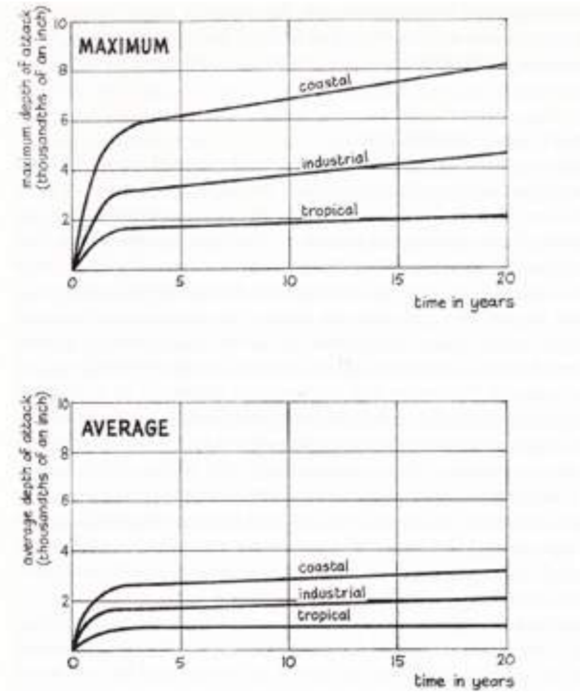


Fig 8.14 Graphs comparing the weathering of aluminium alloy NS3, in diverse climates and locations

The science of the atmospheric oxidation and corrosion of aluminium appears to be well understood, except the composition of electrolyte layers.[12] Following initial oxidation and the formation of an ever-changing electrolyte layer, aluminium alloys progress to a stable state, when considered over a human timeframe rather than a geological timeframe.[13] This research team recommends that the global aluminium fabrication industry should continue long-term exposure testing of aluminium.[14]

Fig 8.15 The Hive, designed by Wolfgang Buttress at the Royal Botanical Gardens, Kew, London 2016-2017

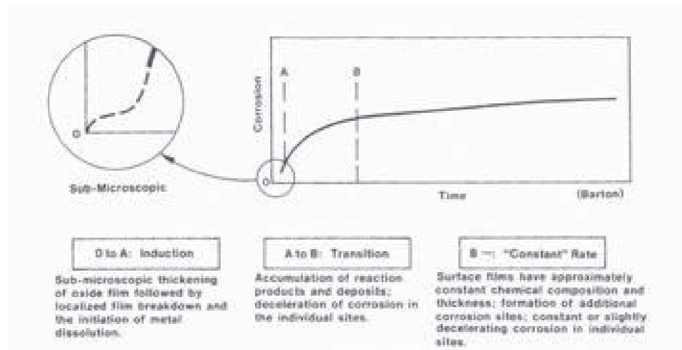


Fig 8.16 The weathering of aluminium alloys based on K. Barton (1976)

The site location and microclimatic considerations need to be considered. The order of risk of corrosion is rural, urban, industrial (highly polluted atmosphere), with coastal plus industrial being the worst case. However, there are examples of cast aluminium proving durable in highly polluted urban situations, for example the Sculpture of Eros, or aluminium roof sheeting in Hamburg Docks, a maritime/polluted context. In Europe, since the tight control of pollution, some consider the difference between rural, urban and industrial to now have less significance in terms of corrosion (BAM 2009).[15] However, this is not the case in developing countries such as China.[16]

Aluminium is more durable when washed by rain and therefore, where possible, architects and engineers should detail buildings to facilitate the washing of the surface by rain. This contrasts with the traditions of masonry construction detailing. The aluminium should be detailed to avoid crevices where water can be trapped rainscreen cladding or sealing with a gasket or silicone seal.[17]

The interim conclusion from TSC Book One *Aluminium and Durability*, include:

- Aluminium based architecture and infrastructure is more durable than predicted.
- Aluminium components within a maintained interior, such as a church or library, appear to have an infinite life expectancy.

Fig 8.17 Chase Manhattan Bank, New York, USA, architect Skidmore, Owings & Merrilll, 1962

- Aluminium components exposed to weather including sun and rain have a life expectancy of over 120 years.
- Service life of aluminium based windows cladding and curtain walling should be increased from 40 years to at least 80 years [although further research is required].

Aluminium and its alloys should no longer be thought of as a new material. Aluminium has a rich and successful track record in architecture and the built environment, with a performative role and a key place in the material culture of humankind.

Fig 8.18 The city of London, circa 2004, following the competition of 30 St Mary Axe, architect, Foster + Partners

‘Manhattan, a young man, a country dweller, a lover of wild uplands, the seas, walking down Park Avenue towards the Pam Am building. Sloping, low winter sunlight. Quietly awestruck – these great canyons! The creation of them – vision, energy, aspiration, beauty!’ James Seaton

Fig 8.19 New York, USA, circa 1977, following the opening of the World Trade Center, architect Minoru Yamasaki

Fig 8.20 Sadly the demolition and recycling of Chetwoods Architects' award winning North Greenwich Sainsbury's was predicted in TSC Book Two *Aluminium Recyclability and Recycling,* demolition took place in the spring of 2016. An over 99% recycling rate of steel and aluminium was recorded on site by contactors Hughes & Salvidge

Aluminium Recyclability and Recycling

Aluminium is almost infinitely recyclable and this is well understood. This research identifies that aluminium-based projects dating back to 1950 that have been disassembled have all been recycled. 1950 is the first year of entries in IAI's global mass flow model. The research reviews the reasons why buildings are demolished and rates of material recovery at the end of use. Key examples of short-life and relocatable architecture are set out, alongside the future role of Design for Disassembly [DfD]. This research also identifies that there is a much wider uptake of cast aluminium components in architecture than may have been expected.

TSC Book Two *Aluminium Recyclability and Recycling* includes a chapter that reveals the use of cast aluminium in architecture, although not as universal as cast aluminium engine blocks in contemporary automobiles, is more extensive than many architects, engineers or commentators realise.[18]

Staircases are a paradigm for the use of castings in architecture as the components of a staircase are, by typology and building regulation, repetitious – the same geometry and performance, step by step. An elegant application of aluminium castings is the elliptical staircase of Tudor House designed by south London based architects Knox Bhavan. This mixed-use project is located in St Peter Port on the Chanel Island of Guernsey and was completed in 2003. Described by architect Knox Bhavan:

> as a helical staircase with a cast aluminium structure, which forms the focal point of a four-story building of office accommodation. The staircase measures 3.2 × 4.4m, and spirals through four storeys under an elliptical rooflight. It is constructed using individual cast aluminium 'wishbones' linked together to form a continuous helix. The stair works in much the same way as a traditional [or seventeenth century] stone cantilever staircase, each individual tread taking support from the step above and below it, with the whole staircase acting as a single continuous structure, further reinforced by the helical handrail above.[19]

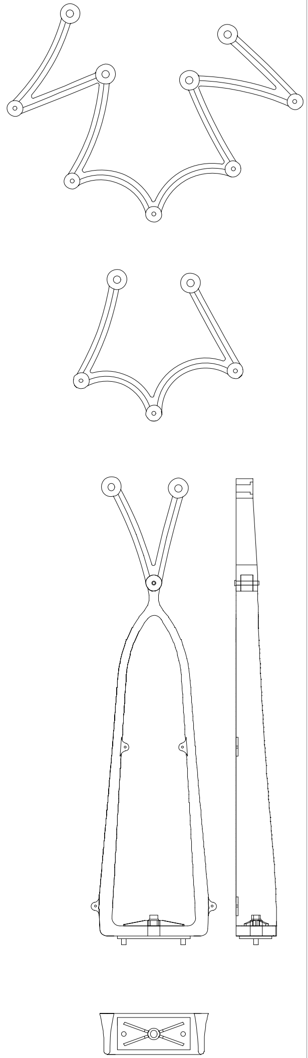


Fig 8.21 Drawing of the components of the cast aluminium stair for Tudor House, architect Knox Bhavan, 2003

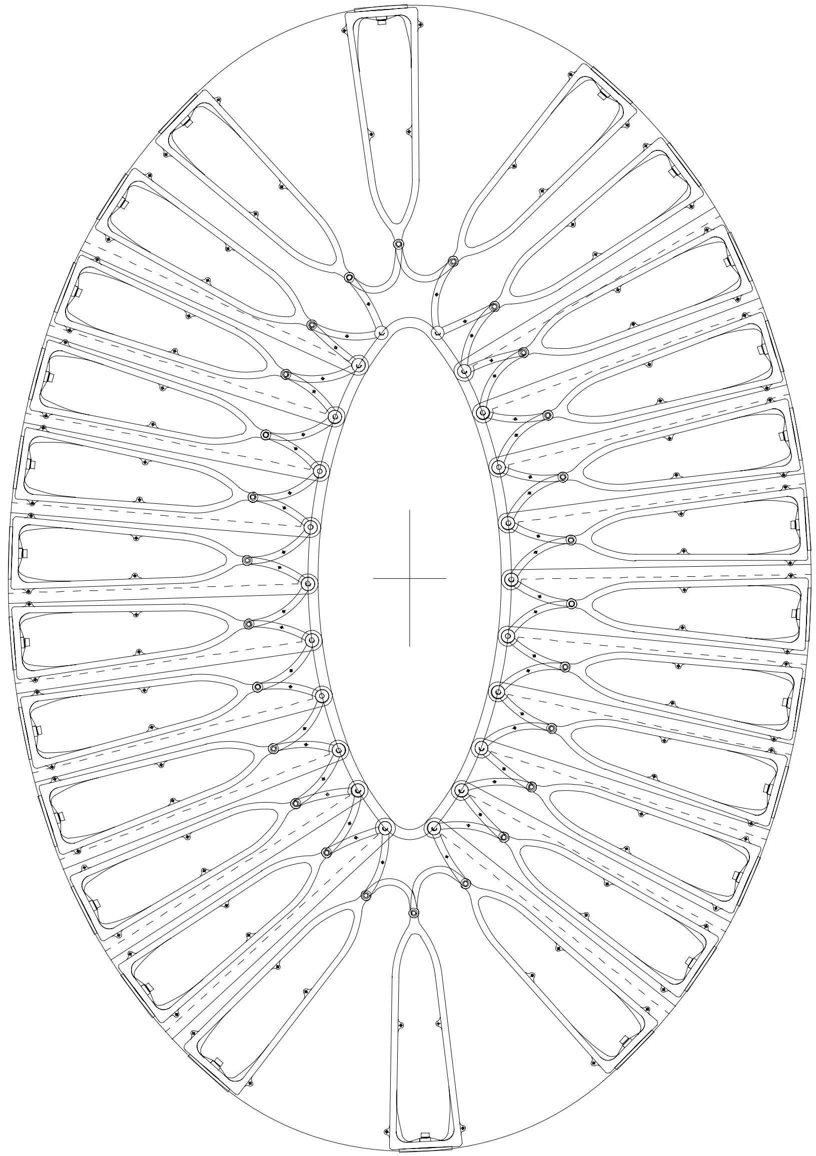


Fig 8.22 Cast aluminium and maple stair in Tudor House, architect Knox Bhavan, 2003

The ‘wishbones’ were sand cast using LM6 aluminium alloy. After the casting was removed from the mould (known as the casting **method**), these casting where then bead blasted to create a fine finish. The treads were cut from maple. Simon Knox hand to be quite hands-on on site to realise this staircase. Knox Bhavan noted that: Breaking new ground with unfamiliar materials for the contractor created unpredictable tensions and anxiety, however we eventually formed an effective team with the subcontractor and finished the staircase.’[20]

Fig 8.23 Cast aluminium components of the stair in Tudor House

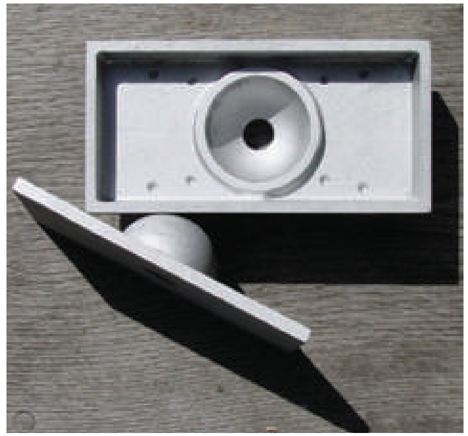


Fig 8.24 First fix cast aluminium components of the stair in Tudor House

Fig 8.25 The first fix cast aluminium components of the stair in Tudor House being installed in the brick drum of the stair tower

One of the most familiar forms of cast aluminium is the coffee pot. More explicitly the cafetière Moka express coffee maker, which was invented in Italy in 1933 by Luigi De Ponti, to maximise the coffee's flavour whilst using as little of the expensive ground beans as possible. Alfonso Bialetti acquired the rights to produce this invention and his company is still producing the Cafetière Junior Express today. Its form has become the type-form of the stovetop espresso maker, with many, many, rival castings throughout the world. In 1985 the great Italian architect Aldo Rossi produced his designs for a cast aluminium La Cupola version of a cafetière express maker for Alessi, which comprises three cast components, a pressed sheet aluminium filter and a polyamide handle, that is insulating and thus stays cool. This Italian design-focused company prides itself on even being able to sell kettles to Sicily, where there is no tradition of boiling water in a closed vessel. Aldo Rossi's design is a miniature cathedral for the domestic kitchen - as if coffee making was a form of mid-morning prayer! Alessi's instructions, reproduced in Fig 8.28, state: 'Aluminium is an excellent conductor of heat and give a characteristic flavour to espresso made in La Cupola….In gastronomic terms, coffee prepared with La Cupola has a fuller flavour than that made with a stainless steel coffee maker.'[21] Despite this, Alessi also make an equally beautiful Aldo Rossi designed espresso maker in stainless steel with a copper bottom – La Conica, which was designed between 1980 and 1983 as part of the *Tea and Coffee Piazza* project.

Fig 8.26 A contemporary version of Bialetti a Cast aluminium Moka express coffee maker,

Fig 8.27 La Cupola – cast aluminium Moka express coffee maker, architect Aldo Rossi for Alessi, 1985

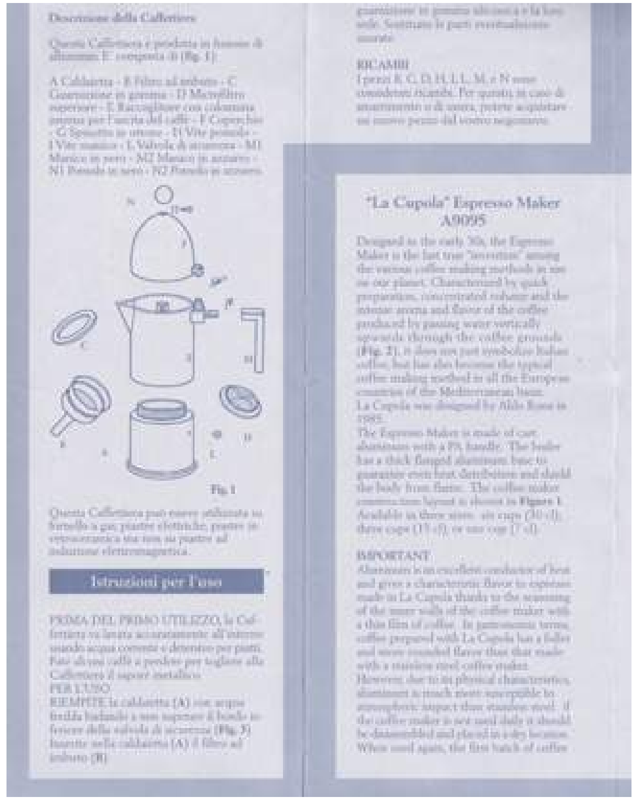


Fig 8.28 An exctract from Alessi's operating instruction for La Cupola – cast aluminium Moka express coffee maker, architect Aldo Rossi, 1985

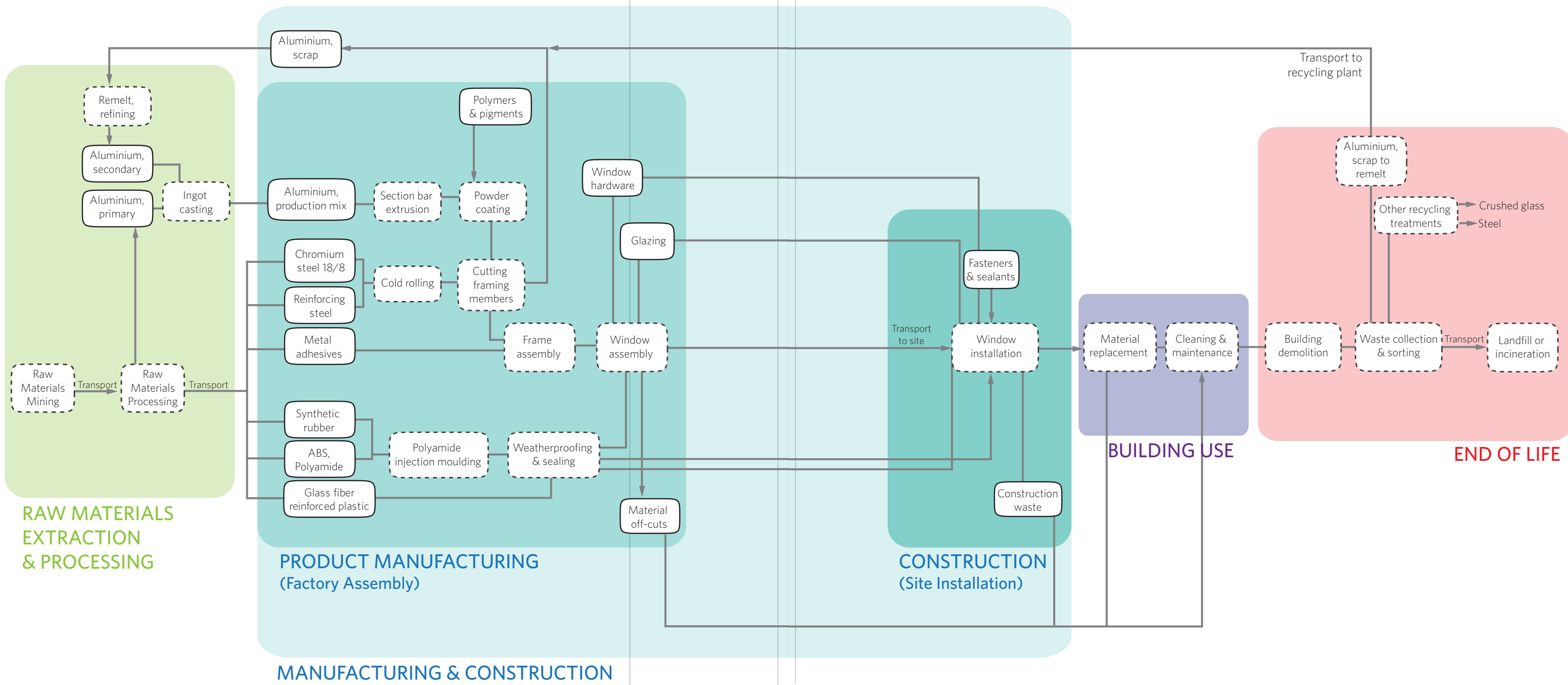
Fig 8.29 Wolfgang Buttress and Julia Barfiled discussing the Hive after the Towards Sustainable Cities Symposium 2016, while Laura Gaskell and Jenny Grewcock disuss its details

Aluminium and Life Cycle Thinking

TSC Book Three *Aluminium and Life Cycle Thinking*, explores the environmental impact of durability and recyclability by investigating an aluminium building product's life cycle, or the stages through which it passes during its lifetime. Raw material extraction, product manufacturing, use and maintenance, and processing at the end of a product's useful life, constitute stages that may be examined in-depth to understand the environmental benefits attributable to an aluminium building product.[22]

Life Cycle Assessment (LCA) is a powerful methodology that provides a scientific basis for comparing the environmental impacts of materials and processes. It renders intelligible the intertwined and layered flows of materials and energy over space and time, allowing designers to move towards a quantifiable

Fig 8.30 Life cycle stages (**ISO 14040**) and system boundaries for a typical aluminium window frame



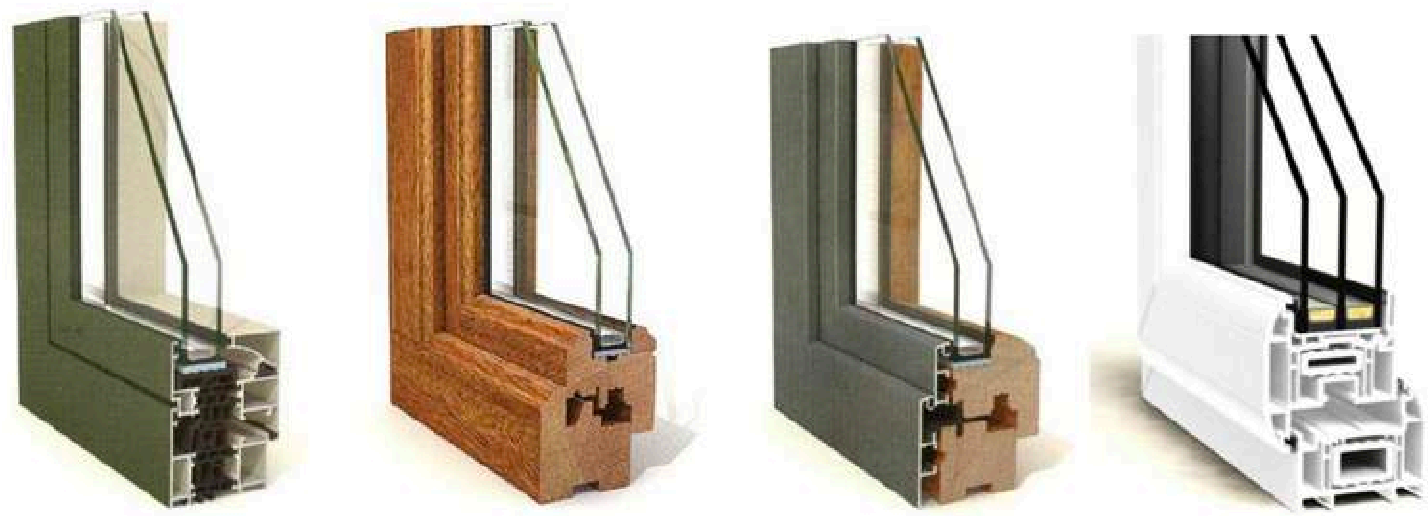


Fig 8.31 Frame types (left to right): aluminium, wood, aluminium-clad wood and PVCu

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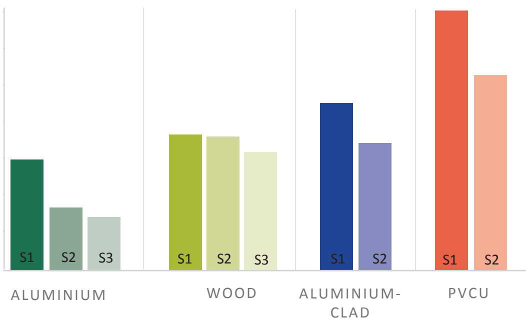
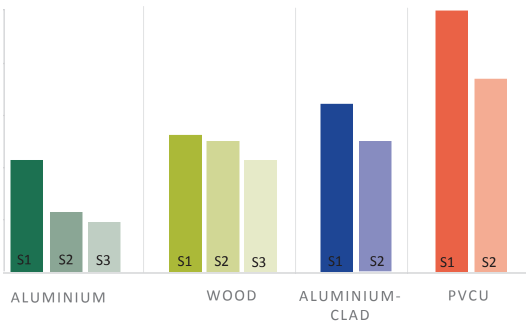
Global Warming Potential



Ozone Depletion



Smog Formation

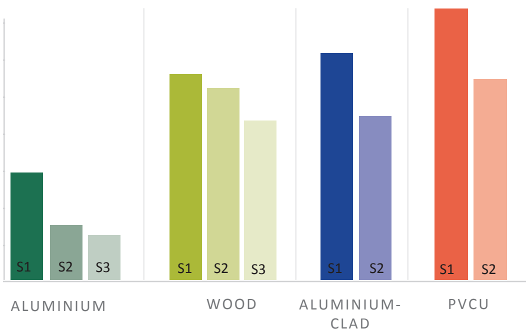
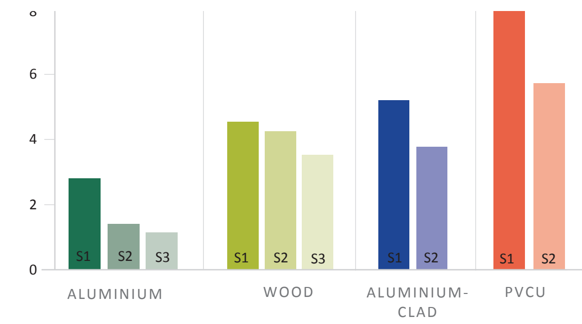
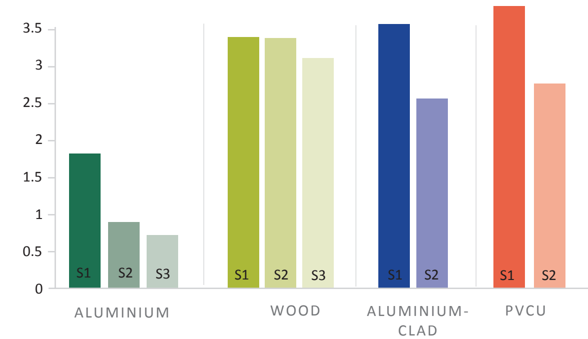


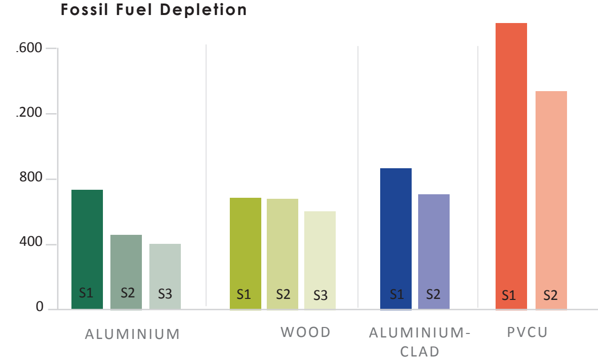
Fig 8.32 Life cycle stages (**ISO 14040**) and system boundaries for a typical aluminium window frame



Eutrophication



Fossil Fuel Depletion



basis for making decisions regarding environmental impact and performance.[23]

This LCA undertaken by Efrie Friedlander, Stephanie Carlisle and Billie Faircloth of KieranTimberlake as part of the TSC research programme compared four types of window framing: thermally broken aluminium, wood, aluminium clad wood and PVCu, over an 80-year building life, allowing for all necessary maintenance. This was based on three scenarios:

- Scenario 1 - Little to no maintenance;
- Scenario 2 - basic maintenance;
- Scenario 3 - High maintenance - long life.

The functional unit used in this LCA used is $1m^2$ of window framing and the software is SimaPro. The practice of LCA is relatively new and it is unusual to include the in-use phase of building components, yet this is very revealing. Results of the Life Cycle Assessment have shown the full cradle-to-grave impacts of aluminium window framing to be far less than previously reported by other studies. When the lifespan of aluminium products are considered across the building's life, the global warming potential of a moderately maintained aluminium window assembly is 68% less than PVC and 50 per cent less than the best case scenario for aluminium-clad wood. Well maintained wood windows were found to have a 7 per cent lower impact from a carbon perspective than the long-life scenario for aluminium-clad wood framing, and to have a nearly 30 per cent lower impact than aluminium-clad wood windows, when the manufacturer guarantee period is used as an estimation of actual life cycle. However, when considering fossil fuel depletion impacts, moderately and well-maintained aluminium windows (scenarios 2 and 3) required less energy to produce and maintain over their lifetime than any of the wood scenarios.[24]

Well maintained aluminium window framing proved to be the least impactful option across all categories, mainly due to the credits delivered at end of life - from recycling aluminium into future building products. Therefore, while this model was initially built to measure the importance of durability and maintenance in the use stage of the life cycle, it has become clear that material reclamation and recycling at end of life is the most significant contributor to reducing the embodied environmental burdens of window framing products.[25] The methodology is sufficiently robust that any party or stakeholder in the construction industry and its supply chain can run this LCA. The LCA contained within TSC Book Three *Aluminium and Life Cycle Thinking* (2015) is the subject of a peer reviewed paper by Efrie Friedlander and Stephanie Carlisle, *The influence of durability and recycling on life cycle impacts of window frame assemblies*.[26]

Fig 8.33 The new American Embassy, London, England, architect KieranTimberlake, 2017

Aluminium: Flexible and Light

TSC Book Four *Aluminium: Flexible and Light*, has the widest scope of all of the books arising from the TSC research programme. In essence it is a contemporary record of the uptake of aluminium in architecture and the built environment. It sets out the selection of aluminium alloys. This book demonstrates the flexibility of aluminium in the many production and fabrication processes that can be used to transform and deploy this light and durable metal, from casting, roll forming, extruding, spinning and direct digital printing. Fabrication processes include: laser and water jet cutting, welding, friction stir welding. The role of aluminium in creating thermally efficient yet highly transparent glazing systems is also discussed.

The key case studies in TSC Book Four *Aluminium: Flexible and Light* demonstrate and quantify the carbon savings arising from the specification of aluminium based architecture including: Kielder Probes by sixteen*(makers), Guy's Hospital Tower by Penoyre & Prasad, dlr Lexicon by Carr Cotter & Naessens, i360 by Marks Barfield Architects and the Large Hadron Collider at CERN. However, it does reach back to key case studies including; the Comet Flight Test Hanger, architect James M. Monro & Son, 1953, which now serves as an elegant daylit tennis club. The Guy's Hospital Tower by Penoyre & Prasad reveals that well designed and specified aluminium overcladding of a 1970s building can achieve a carbon payback period of under 13years.

TSC Book Four *Aluminium: Flexible and Light*, also incorporates a chapter on *Aluminium Bridges.*[27] The history of the application of aluminium to bridge assembly is much more extensive, throughout the world, than many recent academic papers have recorded. This book has telling contributions from Professor Philip Beesley and Professor Brian Ford, commissioned exclusively for this publication.

Towards Sustainable Cities Symposium

The key findings from the *Towards Sustainable Cities* Symposium: 2016 at Royal Botanical Gardens, Kew, London, England, in the autumn of 2016 have been set out in Chapter Six of this book. The proceedings have also been summarised as a video see: https://youtu.be/qqye49QvZQA.

The interview of Wolfgang Buttress by the author in the Hive at Kew Gardens can also be viewed via: https://youtu.be/xM0YEX4NYXc. Michael Stacey Architects produced both videos, in collaboration with *B-made* of the Bartlett University College London and were filmed by William Victor Camilleri.

Fig 8,34 Rogers House, 1970, architect Richard and Su Rogers, restored in 2017 by Gumuchdjian Architects

Aluminium: Sympathetic and Powerful

The core of TSC Book Five *Aluminium: Sympathetic and Powerful* is the findings from the *Towards Sustainable Cities* Symposium: 2016 and related interview with Stephen Kieran, James Timberlake and Billie Faircloth of KieranTimberlake. The case studies in TSC Book Five *Aluminium: Sympathetic and Powerful* demonstrate the potency of aluminium to help address global issues within the built environment in our multi-material world.

Towards Sustainable Cities research programme has quantified the in-use benefits of aluminium in architecture and infrastructure. The *Towards Sustainable Cities Symposium:* 2016 brought together leading architects with artists and engineers, and other key people from the aluminium industry. The author hopes that this was the beginning of an ongoing dialogue, which is essential to promote a more sustainable forward-thinking construction industry, which uses less energy and less material.

To achieve sustainable cities and inform human ecology and peoples well-being and culture, we need to generate a vision of a better future and harness the means of production to deliver this, Lord Norman Foster in 2017 stated:

> to practice architecture, you are planning for the future. You are looking far ahead. So you are trying to work with an environment anticipating change. You have to be an optimist, a utopian…[28]

Fig 8.35 The Snowdon Aviary, with its tubular aluminium alloy structure, at Regents Park Zoo, architect Cedric Price with engineer Frank Newbery and detailed input from Lord Snowdon, completed in 1965. The Snowdon Aviary is Grade II* listed by Historic England (13223695). In 2017 Foster + Partners are in the process of restoring this enclosure and converting to house Colobus monkeys

Timeline of Aluminium up to the Jet Age

1800 – 1960

1808 Aluminium is discovered by Sir Humphry Davy as a constituent of alum, in England

1821 Pierre Berthier discovers bauxite ore in Les Baux-de-Provence, southern France

1825 H. C. Ørsted produces significant quantities of aluminium, in Denmark

1827 Friedrich Wöhler isolates aluminium, in Germany

1854 Henri Étienne Sainte-Claire Deville enhances Wöhler's method of isolating aluminium and chemical production of aluminium commences in France

1855 Aluminium spoons and forks used by visiting dignitaries at the Court of Napoléon III, in France

1858–60 Aluminium casting of Diane de Gabies by Paul Morin et Cie, in France

1884 Cast aluminium pyramid cap to the Washington Monument, in USA

1886 Hall-Héroult process – affordable volume production of aluminium invented by Charles Martin Hall and Paul Héroult

1887 Bauxite refining, the Bayer process is invented & patented by Austrian scientist Karl Josef Bayer

1888 Pittsburgh Reduction Company founded to develop the Hall-Héroult process

1890 First use of aluminium for overhead electric power cables

1891 First aluminium boat fabricated in Switzerland

1892 Cast aluminium sculpture of Eros at Piccadilly Circus, London

1895 Aluminium ceiling installed at Church of St Edmund, King & Martyr, Derbyshire, Fenny Bentley

1897 Aluminium sheet cladding of the cupola of the church of San Gioacchino, Rome

1902 Aluminium is the key material in the interior of St Mary the Virgin, Great Warley, Essex

1903 First powered flight by Wright brothers, Kill Devil Hills, USA, using a cast aluminium engine

1906 Alfred Wilm invents Duraluminium in Germany

1906 Otto Wagner's Postsparkasse, Vienna – cast and sheet aluminium

1920s Development of anodising and aluminium extrusion processes

1931 Empire State Building, New York, USA, by William F. Lamb: cast aluminium spandrel panels

1934 Anodised aluminium windows installed at University of Cambridge Library, architect Sir Giles Gilbert Scott

1940 Anodised aluminium windows installed at New Bodleian Library, architect Sir Giles Gilbert Scott

1949 Unitised aluminium curtain walling by Jean Prouvé for Fédération du Batiment Office, Paris

1950s Pioneering of aluminium curtain walling in USA

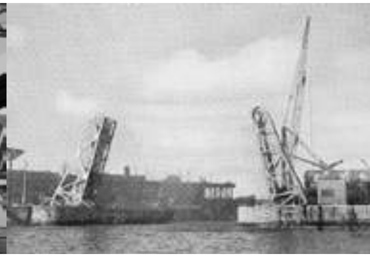
1950 UN Secretariat Building, New York, clad in aluminium curtain walling, executive architects Harrison & Abramovitz

1953 Alcoa Building 'The worlds first aluminum skyscraper', Pittsburgh, by Harrison & Abramovitz

1954 Jean Prouvé's Aluminium Centenary Pavilion is built to celebrate the 100th anniversary of the industrial production of aluminium in France

1957 Jean Prouvé designs extruded aluminium curtain walling for CIMT

Timeline of Aluminium Bridges from the Jazz Age to the Digital Age



1933 — 2000

- **1933** Aluminium decking replaces the timber and steel decks of Smithfield Street Bridge, Pittsburgh, built in 1882
- **1946** First all-aluminium bridge, Grasse River Bridge, Massena, New York, spanning 30.5m
- **1948** World first aluminium bascule bridge: Hendon Dock Bridge, Sunderland is built by Head, Wrightson & Co of Stockton
- **1950** Arvida Bridge aluminium road bridge is still performing well today, spanning 88.4m
- **1953** Aluminium bascule bridge of Victoria Dock, Aberdeen, opened by the Queen Mother
- **1956** First aluminium road bridge in Europe: Schwansbell Bridge, spanning over the Datteln-Hamm Canal near Lünen, Germany, it is still in use today
- **1975** In France, three suspension bridges: Montmerle and Trevoux spanning the Saône river and Groslée on the Rhône river are restored using aluminium structural decks
- **1987** In Sweden, Sapa develop an extruded aluminium bridge deck system, inventor Lars Svensson
- **1989** Sapa aluminium bridge deck system installed on the Tottnäs Bridge, Stockholms Län, Sweden
- **1995** Norway's first aluminium road bridge opens in Vefsn, Norway
- **1996** Reynolds Metals Company install a new aluminium deck on the historic suspension bridge, Corbin Bridge, Pennsylvania, USA
- **1999** Lockmeadow Footbridge, Maidstone, a patented aluminium bridge deck designed and developed by WilkinsonEyre with engineer Flint & Neill
- **2000** Millennium Bridge, London, designed by Foster + Partners with engineer Arup
- **2001** Millennium Bridge, Gateshead, designed by WilkinsonEyre with engineer Gifford & Partners
- **2003** Bridge of Aspiration, London, designed by WilkinsonEyre with engineer Flint & Neill

Notes

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19 Knox Bhavan (2016), *craft, material, detail: Knox Bhavan*, Artifice, London, p.158.
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22 S. Carlisle, E. Friedlander and B. Faircloth (2015), *Aluminium and Life Cycle Thinking: Towards Sustainable Cities*, Cwningen Press, Llundain, p.11.
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Fig 8.38 **Professor Michael Stacey and the TSC research team has visited as many of the projects featured in the Towards Sustainable Cities research programme publications as is humanly possible. Some projects have been revisited many times**

Glossary

Age Hardening: precipitation from solid solution resulting in a change in properties of a metal alloy, usually occurring slowly at room temperature (natural ageing) and more rapidly at elevated temperatures (artificial ageing), typically resulting in components with higher yield stress.

Air infiltration rate: is the tested measure of the rate of airflow through a building fabric and it is typically measured in $m^3/m^2/hr$.

Alloy: combination of a metal with other chemical elements (or chemical element) to form enhanced properties, with the parent metal such as aluminium as the primary material.

Angularity: conformity to, or deviation from, specified angular dimensions in the cross section of a shape or bar.

Annealing: heating and gradual cooling to modify the properties of a metal, alloy or glass, to attain acceptably low internal stresses or desired structure or both.

Anodising: an electrochemical method of producing an integral oxide film on aluminium surfaces.

Anodising quality: describes material with characteristics that make it suitable for visible anodising, after appropriate preliminary treatment.

Anthropocene: proposed term for the current geological epoch where humankind has altered the environment and ecology of Earth to the extent that it is being recorded in the Earth's crust.

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

Billet: a cast aluminium product suitable to use in an extrusion press, usually of circular cross-section but may also be rectangular, or elliptical.

Bow: the deviation in the form of an arc of the longitudinal axis of a product.

Buffing: a mechanical finishing operation in which fine abrasives are applied to a metal surface by rotating fabric wheels for the purpose of developing a lustrous finish.

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.[1]

Burr: a thin ridge of roughness left by a cutting operation such as routing, punching, drilling or sawing.

Circumscribing circle diameter (CCD): the smallest circle that will contain the cross section of an extrusion, designated by its diameter.

Circular Economy: a regenerative system in which resource input, waste, emissions, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling.

Cold work: plastic deformation of metal at such temperature and rate that strain hardening occurs.

Composite construction: the combination of materials with very different mechanical properties to form a single component.

Concavity: a concave departure from flat.

Concentricity: conformity to a common centre, for example, the inner and outer walls of round tube.

Container: a hollow cylinder in an extrusion press from which the billet is extruded, the container can be rectangular or elliptical.

Conversion coating: treatment of material with chemical solutions by dipping or spraying to increase the surface adhesion of paint.

Corrosion: the deterioration of metal by a chemical or electrochemical reaction with its environment.

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.[2]

Delta T, ΔT: is a the temperature difference across building fabric between the internal temperature and external temperature)

Die-casting: metal casting formed in a mould, typically steel, appropriate for high volume production.

Direct extrusion: a process in which a billet, in a heavy walled container, is forced under pressure through an aperture in a stationary die.

Draft angle: taper on vertical surface of a pattern or mould to per mit easy withdrawal of pattern or product from mould or die.

Drawing: the process of pulling material through a die to reduce the size and change the cross section.

Drift test: a routine sampling test carried out on hollow sections produced by bridge or porthole methods, in which a tapered mandrel is driven into the end of the section until it tears or splits.

Electrolytic colouring: a two-stage colour anodising process.

Etching: the production of a uniform matt finish by controlled chemical (acid or alkali) treatment.

Etching test: the treatment of a sample using a chemical reagent to reveal the macro-structure of the material.

Elastomer: this is the general term used to describe a material, synthetic or naturally occurring, which has rubbery or elastic properties.

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.

Extrusion die: metal plate or block, typically steel, used for forming materials in the extrusion process, where the cross section of the extruded material takes the negative form of the die.

Extrusion ratio: the ratio of the cross-sectional area of the extrusion container to that of the extruded section (or sections in the case of multi-cavity dies).

Fillet: a concave junction between two surfaces.

Free machining alloy: an alloy designed to give small broken chips, superior finish and/or longer tool life.

Full heat treatment: solution heat treatment followed by artificial ageing.

G-value indicates the degree to which glazing transmits heat from sunlight, expressed in a number between 0 and 1. The lower the g-value, the less heat is transmitted.

Grain growth: the coarsening of the grain structure of a metal occurring under certain conditions of heating.

Grain size: the main size of the grain structure of a metal, usually expressed in terms of the number of grains per unit area or as the mean grain diameter.

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.

Hardness:the resistance of a metal to plastic deformation usually measured by controlled indentation.

Heat treatable: an alloy capable of being strengthened by appropriate heat treatment.

Holocene: a geological epoch that began about 11,700 years before 2000AD, and simply means *entirely recent*, in ancient Greek.

Homogenisation: a high temperature soaking treatment to eliminate or reduce segregation by diffusion.

Indirect method: a process whereby a moving die, located at the end of a hollow ram, is forced against a stationery billet.

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 end-of-life processes are uncertain. However, cradle-to-gate 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).[3]
>
> **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.[4]

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.[5]

Light transmission: a Lt-value indicates the amount of visible light that progresses through a glazed façade.

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

Logs: a cast aluminium product suitable for extrusion shipped in lengths of 7-8 metres.

Lost foam casting: a metal casting formed in a ceramic 'jacket' or investment mould from which the foam pattern is vaporised by the action of the hot metal as it is cast.

Lost wax casting: a metal casting formed in a ceramic 'jacket' or investment mould from which the wax pattern has been removed by heating, prior to casting.

Mandrel: core or former used in filament winding or the extrusion of hollow sections.

Mean diameter: the sum of any two diameters at right angles divided by two.

Mean wall thickness: the sum of the wall thickness of tube, measured at the ends of any two diameters at right angles, divided by four.

Mechanical properties: those properties of a material that are associated with elastic and inelastic reactions when force is applied, or that involve the relationship between stress and strain. These properties are often incorrectly referred to as 'physical properties'.

Method: the system of gates, feeders and risers used to feed a mould cavity to ensure an even distribution of metal with a constant rate of solidification, avoiding the formation of unwanted cavities in a casting is called the method.

MIG welding: in Metal Inert Gas welding a direct current of reverse polarity is struck between the work piece and a continuously feed welding rod, which acts as filler and electrode. Penetration cannot be as closely controlled as in TIG welding.

Monocoque: a structure in which the stiffness is generated by the form of the skins or shell only. Monocoque is literally French for 'single shell'.

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.

Overcladding: 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.

Pattern: a pattern is a positive of the finished cast component and incorporates the feeders and risers. It is used to form the mould cavity.

Pit corrosion: localised corrosion resulting in small pits in a metal surface.

Platen press: used for laminating, a platen press comprises a rigid frame that supports two rigid and flat plates or platens, which can be brought together to under pressure. The flat plates can be heated to reduce cure time.

Porthole die: an extrusion die, also known as a hollow die, which incorporates a mandrel as an integral part. A bridge die and a spider die are special forms of a porthole die – all used to produce extruded hollow sections from solid billets.

Polymer: organic chemical compound of molecule(s) formed from repeated units or chains of smaller molecules or atoms.

Power mix: 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.

Press brake: method of forming sheet metals into profiled linear component(s) using the action of a top and bottom tool, forming the component under pressure.

Pultrusion: lineal component, typically incorporating fibre reinforcement, which is also drawn through a die.

Quenching: controlled rapid cooling from an elevated temperature by contact with a liquid, gas or solid.

Rainscreen cladding: an external cladding that forms an airspace that is drained, ventilated and can be pressure equalised. It protects the inner layers from heavy wetting and solar radiation. Typically the joints are open. The thermal performance and control of permeability are within the inner layer of the wall and do not form part of the rainscreen.

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

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.

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.

Roll forming: a method of producing a profiled linear sheet metal component by the progressive development of the shape by roll form tools.

Sand casting: a metal casting formed in a sand mould.

Semis; (short for semi-fabricated or semi-finished products). Semis are intermediate products that require further processing before being a finished good. For aluminium and aluminium alloys these products include sheet, plate, coil, extrusions, tube or wire, but also include unfinished castings.

Spinning: a flat sheet of the metal is rotated at speed and formed over a hardwood or steel tool. Forming components with a rotated geometry only.

Strain: defines how far the atoms or molecules of a solid material is being pulled apart by an external force.

$$\text{Strain} = \boldsymbol{e} = \frac{\text{increase in length}}{\text{original length}} = \frac{\Delta \boldsymbol{L}}{\boldsymbol{L}}$$

Strain is a ratio and therefore has no units.

Stress: Is a measure of how hard the atoms and molecules of a solid material are being pulled apart or pushed together as a result of an external force.

$$\text{Stress} = \boldsymbol{s} = \frac{\text{Force}}{\text{Area}} = \frac{\boldsymbol{F}}{\boldsymbol{A}}$$

Stress is measured in Nm^{-2}.

Solution heat treatment: a thermal treatment in which an alloy is heated to a suitable temperature and held for sufficient time to allow soluble constituents to enter into solid solution, where they are retained in a supersaturated state after quenching.

Superplastic alloy: an alloy with high ductility, which is the product of a fine and stabilised grain structure. A superplastic alloy is capable of elongation of up to 1000 per cent.

Technosphere: The sphere or realm of human technological activity; the technologically modified environment.

Temper: stable level of mechanical properties produced in a metal or alloy by mechanical or thermal treatment(s).

TIG welding: in Tungsten Inert Gas welding, fusion between the metal components is induced by the arc, which burns between the electrode and the work piece, with filler rod being fed independently. This is shielded from the atmosphere by an inert gas such as argon.

Thermal conductivity or k-value is a measure of how easily heat passes through $1m^2$ of material 1m thick under the influence of 1°C temperature difference and is measured in W/mK.

Thermal resistance or R-value: the measure of resistance to heat flow through a material, measured in m^2K/W. U-Value is the inverse sum of the thermal resistances of all of the layers of a construction including the inner and outer surfaces.

Thermal transmittance or U-value: the property of a building fabric element, which describes the steady state heat flow, denoted by the symbol U, hence U-value, measured in W/m^2K. It is defined as the quantity of heat, which flows in unit time through one unit area of an element, when the difference between the temperature of the air on the two sides of the element is 1°C.

Specific U-value terminology:

Ucw: thermal transmittance of the total curtain walling (cw = curtain walling).
Ug: thermal transmittance of the glass or glazing (g = glass).
Uf: thermal transmittance of the frame (f = frame).
and
Uw: thermal transmittance of the total window (w = window).

Twist: a winding departure from a flat plane.

Ultimate tensile strength: the maximum stress that a material can sustain in tension under a gradual and uniformly applied load.

Win: In the context of mining win means to extract and process an ore to produce the desired mineral or metal.

Young's modulus of Elasticity: expresses how stiff or floppy a material is, designated by E.

Young's Modulus of Elasticity $$E = \frac{\text{Stress}}{\text{Strain}}$$

Notes

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

2 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/ les/guides/dfd.pdf (accessed November 2014) for extensive use of adapted excerpts.

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

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

5 Ibid.

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aluminium: sympathetic and powerful

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 the 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 Regional Rail Stations, Cardiff Bridges and Ballingdon Bridge. The 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

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Towards Sustainable Cities Symposium 2016

Royal Botanical Gardens, Kew, London, England, 31 October 2016

Speakers:

Chris Bayliss	International Aluminium Institute
Wolfgang Buttress	Wolfgang Buttress Studio
Professor Michael Stacey	Michael Stacey Architects
Billie Faircloth	KieranTimberlake
Jim Eyre	WilkinsonEyre

Panellists:

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Mo Panam	Barley Chalu
Hilde Merete Aasheim	Norsk Hydro
Jo Bacon	Allies & Morrison
Julia Barfield	Marks Barfield Architects
Ian Crockford	Marks Barfield Architects
Egil Hogna	Sapa AB

Participants:

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Ben Kahrs	Alcoa Corporation
Esther Worthington	AHMM
Peter Wasow	Alumina Limited
Andrew Wood	Alumina Limited
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Tim Murray	Aluminerie Alouette Inc.
Jan Lukaszewski	ALFED
Nadine Bloxsome	Aluminium International Today
Ao Hong	Aluminum Corporation of China
Yan Shanfeng	Aluminum Corporation of China
Zeng Qingmeng	Aluminum Corporation of China
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Wong Yuting	China Hongqiao Group
Justin Furness	Council for Aluminium in Building
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Nadine Faldo	International Aluminium Institute
Ron Knapp	International Aluminium Institute
Pernelle Nunez	International Aluminium Institute
Katy Tsesmelis	International Aluminium Institute
Linlin Wu	International Aluminium Institute
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Hideki Amimura	Nippon Light Metal
Masafumi Hisatsune	Nippon Light Metal
Ichiro Okamoto	Nippon Light Metal
Neil Allfrey	Penoyre & Prasad
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Khalid Laram	Rio Qatalum
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Khaled Alohali	Saudi Arabian Mining Company (Ma'aden)
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Mark McGee	South32
Masahiko Shinada	Sumitomo Chemical Company Limited
Ryan Olsen	The Aluminum Association
John Hannagan	UC Rusal
Oleg Mukhamedshin	UC Rusal
Ricardo Carvalho	Votorantim

Michael Stacey Architects

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WORLD ALUMINIUM

aluminium: sympathetic and powerful

publication series

Towards Sustainable Cities: Publications

Aluminium and Durability (2014)

The durability of aluminium is probably one of the most important qualities of this metal when used to form architecture and infrastructure.

Charting almost one hundred years of the use of aluminium in architecture and the built environment, based on 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. A second edition of *Aluminium and Durability* was published in 2015.

Written and edited by Michael Stacey.

Aluminium Recyclability and Recycling (2015)

Aluminium is almost infinitely recyclable and this is well understood. This research identifies that aluminium-based projects dating back to 1950 that have been disassembled have all been recycled. 1950 is the first year of entries in IAI's global mass flow model. The research reviews the reasons why buildings are demolished and rates of material recovery at the end of use. Key examples of short-life and relocatable architecture are set out, alongside the future role of Design for Disassembly [DfD]. This research also identifies that there is a much wider uptake of cast aluminium components in architecture than may have been expected.

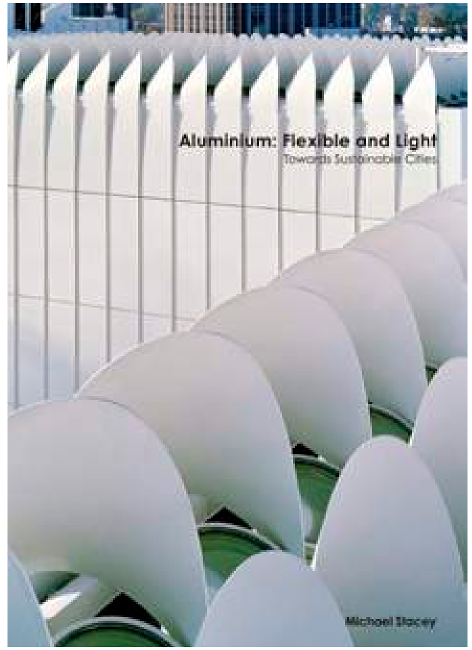
Written by Michael Stacey.

All of the TSC books can be downloaded for free via:
www.world-aluminium.org

Aluminium and Life Cycle Thinking (2015)

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.

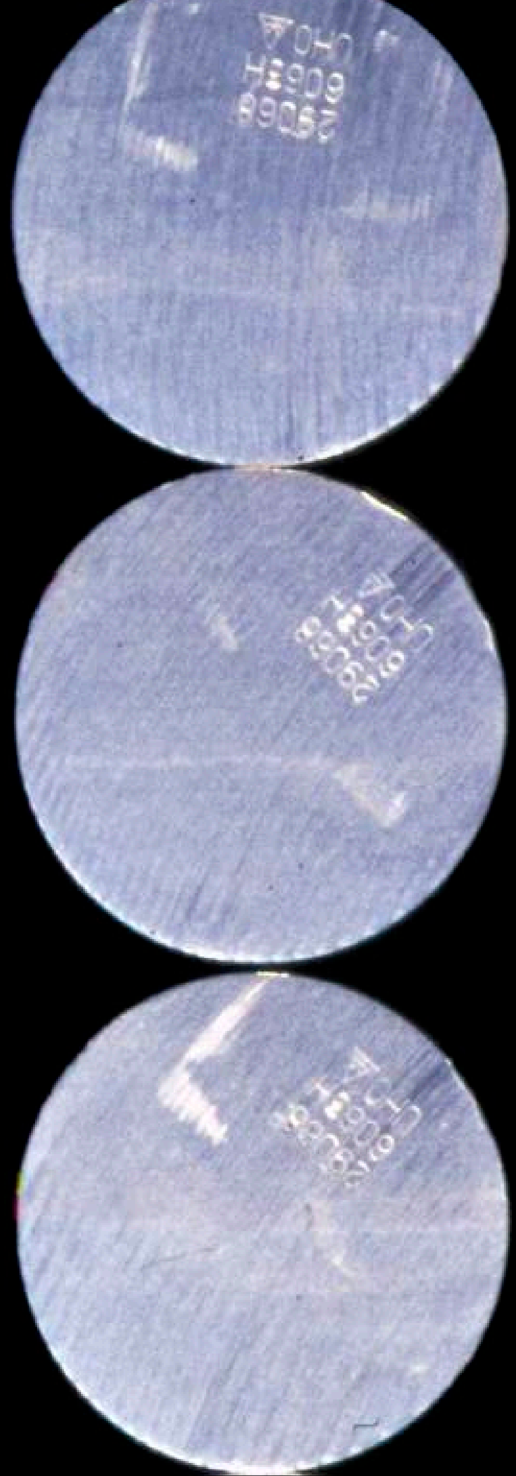


Aluminium: Flexible and Light (2016)

Demonstrates the flexibility of aluminium in the many production and fabrication processes that can be used to transform and deploy this light and durable metal, from casting, roll forming, extruding, spinning and direct digital printing. Fabrication processes include: laser and water jet cutting, welding, friction stir welding. The role of aluminium in creating thermally efficient yet highly transparent glazing systems is also discussed. Key case studies demonstrating and quantifying the carbon savings arising from the specification of aluminium based architecture include: Kielder Probes by sixteen*(makers), Guy's Hospital Tower by Penoyre & Prasad, dlr Lexicon by Carr Cotter & Naessens, i360 by Marks Barfield Architects and the Large Hadron Collider at CERN.

Written by Michael Stacey.

The Hive the UK Pavilion at the Milan Expo 2015, designed by artist Wolfgang Buttress



Aluminium: Sympathetic and Powerful, written by Michael Stacey, with contributions from everyone who attended the Towards Sustainable Cities Symposium 2016, at the Royal Botanical Gardens, Kew, key contributors included: Wolfgang Buttress, Hilde Merete Aashein, Julia Barfield, Wolfgang Buttress and Jim Eyre, and from the research team: Laura Gaskell, Jenney Grewcock, Philip Noone, Michael Ramwell, and Billie Faircloth, James Timberlake and Stephen Kieran. The symposium was recorded in sound and vision by B-Made of The Bartlett School of Architecture at University College London (UCL).

This fifth book fifth in the series 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, the Architecture and Tectonics Research Group [ATRG] at the University of Nottingham and B-made of the Bartlett.

The **Towards Sustainable Cities Research Programme** is structured around the primary benefits of aluminium, as articulated by the *Future Build 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 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. Case studies demonstrate and quantifying the carbon savings arising from the specification of aluminium based architecture.

"The TSC research project is fantastic; many architects have quite limited understanding of the aluminium and its durability and recyclability, all of the qualities we learnt about at this symposium." Julia Barfield MBE

"Aluminium is an exceptional material because of its shear versatility. Used carefully, it can achieve a feeling of lightness, which is a form of power in itself. Not used carefully, it can be very heavy and appear heavier than steel!" Jim Eyre MBE