Towards sustainable cities

The in use benefits of aluminium in architecture, by Chris Bayliss*, Professor Michael Stacey** & Stephanie Carlisle***

On 24 October 1946, Oxford’s New Bodleian Library was officially opened by King George VI. It was not a particularly auspicious occasion – the ceremonial key broke in the lock and the King and Queen effectively had to break in to the University’s latest (and much needed) asset. The silver key has sat in the Library’s treasury ever since, its (not very) useful life over with almost as soon as it began. The Giles Gilbert Scott designed building, however, has remained a protective and productive centre of learning for over 70 years and, as of March 2015, has started a second life as the Weston Library, following an £80 million refurbishment by architects Wilkinson Eyre.

Many elements of Sir Giles’ original building remain, however, and among these – integral to the design and function of the original, and the upgraded Library – are the windows. Aluminium windows. Anodised aluminium windows, installed in 1939, and which are expected to have a service life of at least another half century.

Sixty years after the opening of the original Bodleian Library and three and a half thousand miles away in New York, an architectural project with a much shorter lifespan, but with an equally critical role for aluminium, was underway. In 2008, 500 architects were asked to submit proposals for full-scale designs reflecting the current state and future potential of prefabricated architecture to be evaluated for exhibition at The Museum of Modern Art in Manhattan. One of five selected for construction on a site adjacent to the museum, the Cellophane House™ was a five-story home with two bedrooms, two bathrooms, living and dining space, a roof terrace and a carport. Its assembly was more like that of a car than a traditional building. The whole construction was broken down into integrated assemblies, called “chunks,” that were fabricated off site, then delivered via trailers to the site and stacked on top of each other with a crane. Eighty per cent of the construction was completed in six days.

Materials were selected to be lightweight, minimising embodied energy, and reusable within existing recycling streams. A light, adaptable, five storey aluminium frame, strengthened by custom-designed steel connectors, formed the skeleton of the building, with a SmartWrap™ skin enveloping the structure and interior floors, ceilings, and partitions made of structural plastic. Cellophane House™ was designed for...

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adaptability, able to respond to a range of climatic factors, solar orientations, slopes and adjacencies, which differ from site to site. The skin was envisioned as a filter, selectively letting in daylight and seasonal heat and keeping out UV light and hot or cold air, depending on the season, with the narrow profile of the aluminium frame enabling this functionality.

The final experiment for this adaptable, lightweight home was its disassembly. The house was deglazed, un-stacked, and disassembled at ground level using basic handheld tools. Parts were organised on pallets and removed from the site in two days. Virtually no waste was generated, and 100% of the energy embodied in materials was recovered. The only remnant was a patch of gravel in an asphalt lot.

**Aluminium and green buildings**

These examples of aluminium’s durability, lightness and strength, adaptability and reusability/recyclability in the building and construction sector, along with other demonstrations of the metal’s unique combination of properties, led the International Aluminium Institute to begin to document case studies of aluminium usage in architecture in its *Aluminium & Green Building* website (part of *The Aluminium Story*) and subsequently to develop a three year research programme on aluminium and the built environment: *Towards Sustainable Cities*. About to launch the fourth report in a series of five, *Towards Sustainable Cities* is being undertaken by Michael Stacey Architects (whose portfolio includes a number of award winning, aluminium-intensive designs), with KieranTimberlake (the designers of the Cellophane House and architect of the forthcoming US Embassy in London) and the Architecture and Tectonic Research Group of the University of Nottingham.

A primary aim of this research is to quantify the in use benefits arising from the specification of aluminium in architecture and the built environment, to complement the relatively well understood energy (and associated emissions and waste) savings from the use of aluminium applications in transport lightweighting 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 as now over half of humanity lives in urban areas.

Buildings account for up to 40% of global energy consumption and thus improving the overall systemic efficiency of buildings and their contents, while maintaining their value as living and working spaces, is a key aspect of sustainability. Given the ongoing growth
in urban populations globally, the potential for emerging economies to design and realise “green cities” from the bottom up is a positive opportunity for decoupling human wellbeing from environmental impact.

The most energy efficient buildings start with aluminium – 25% of global aluminium demand is from the construction sector. Aluminium components and designs optimise natural lighting and shade, enhance energy management and support designs that make the most of the physical environment. Being durable and corrosion resistant, aluminium components in buildings contribute to reduced maintenance over time, while the metal’s unmatched recyclability gives architects a key sustainability design tool. Aluminium’s high strength-to-weight ratio makes it possible to design light structures with exceptional stability allowing for narrow window and curtain wall frames, maximising solar gains for given outer dimensions. Aluminium’s light weight also makes it cheaper and easier to transport and handle safely on site. In Europe, around 95% of architectural aluminium is collected and recycled. Globally, buildings contain over 200 million tonnes of aluminium, which will be available for recycling by future generations time after time - an energy bank for the future.

The research programme has been structured as a series of studies based on the properties that aluminium brings to construction applications – durability, recyclability, flexibility, lightness/strength and the potential for energy saving (and energy producing) buildings that are sympathetic to their environment. The first report, Aluminium and Durability (Stacey, 2014), amasses case study buildings that pioneered aluminium’s use, alongside exemplary historical and contemporary examples, to evidence life expectancy and service life for aluminium building components.

The second report, Aluminium Recyclability and Recycling (Stacey, 2015), documents current building demolition protocols that include the collection, reuse and recycling of building materials and components. It gathers case study buildings that demonstrate re-glazing/re-fenestration, over cladding, retrofit, deep-retrofit, and short-life building techniques – all dependent upon aluminium’s economic value and ability to be collected and continuously recycled.

Aluminium and Life Cycle Thinking (Carlisle, Friedlander & Faircloth, 2015), the third report in the series, 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 materials 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.

The forthcoming Aluminium: Flexible and Light will explore the lightweight potential of aluminium structures – including bridges and formwork – as well as the flexibility that the material offers architects to design adaptable, energy-saving buildings, that can be constructed (and demolished) more quickly, safely and cost effectively than traditional designs.

A final report, Aluminium: Powerful and Sympathetic is planned for later in 2016.

Service Life
The durability research stream began with a global survey of the last 120 years’ use of aluminium in architecture and infrastructure, identifying over fifty aluminium pioneers from the 1897 dome of San Gioacchino in Prati Church, Rome, the late 19th/early 20th century English parish churches of St Mary’s Great Warley and St Edmund, King and Martyr Fenny Bentley and the imposing 1906 Postparkasse of Otto Wagner in Vienna to the Hong Kong and Shanghai Bank by Foster Associates, completed in 1985. The following research question was formulated out of the results of this survey: “are there aluminium based projects that are fit and forgotten; functioning well for the owners and users, whilst out-performing the contract guarantees provided when they were assembled”.

To answer this question, twelve projects were selected as case studies, each of them award winning and/or of historical significance and all over 25 years old. During 2012 and 2013 all twelve projects, including the Alcoa Building, were the subject of a literature review, visual inspection and photographic survey.

From these projects, three were selected for in situ non-destructive testing of their finishes, including the windows of the Bodleian Library. The timescales for the durability of aluminium established by the research, including physical testing, demonstrate that the service life of aluminium applications (in particular windows), used by organisations including building research establishments, should be revised upwards from 40 years to at least 80 years. Site or programme specific issues may limit these life expectancies, such as the use of aluminium within a swimming pool or an aggressive industrial interior. For polyester powder coating the recoating methods need to be well specified, but the oldest polyester powder coating still in service in this study is 43 years old and has not been recoated, while the guarantees offered in 1973 were only 10 years. The oldest example of PVDF coated aluminium in this study is 28 years old and looks very similar in appearance to when it was first inspected in 1988.

The interim conclusion of this part of the research suggests that well specified and well-detailed aluminium architecture should be considered to be very durable and have a very long life expectancy. Aluminium components within a maintained interior, such as a church or library, appear to have an infinite life expectancy, while those exposed to the elements have a life expectancy of over 120 years.

Life Cycle Assessment
Life cycle thinking encourages actors across the entire value chain – manufacturers, professional architects and engineers, contractors and building owners – to be mindful of the life history of any manufactured product, and more specifically, to understand the inputs (including resources such as energy and water) and outputs (emissions to the environment) that result from the transformation of materials into product, from product to service, and from service to disposal.

If life cycle thinking is a framework through which a building product’s life history is given consideration, Life Cycle Assessment, or LCA, is the modelling method used to quantify a product’s environmental impacts. LCA models may be used to study specific questions regarding the environmental impacts of a given building product across selected stages of product life. Increasingly, LCA
is a modelling practice being adopted by, or mandated to, architects and engineers during the design process in order to give consideration to environmental impact information during the selection of materials, components and assemblies. The third report in the Towards Sustainable Cities contains a series of modelling studies, using comparative LCA to explore key issues in the environmental impacts of building materials: Recycled Content and End-of-Life Recycling scenarios; service life, maintenance and durability; manufacturing inputs and service life sensitivity analysis. All three LCAs make use of a simple and common architectural component, window framing, as the object of comparison, allowing for exploration of multiple materials and assembly techniques. The results and outcomes of the study of service life, maintenance and durability are presented here.

Modelling Durability

Aluminium, wood, aluminium-clad wood and PVCu windows were examined using three different use scenarios associated with different maintenance regimes.

Scenario 1 represents the most conservative estimate of window life; it assumes that no significant repair or replacement activities are conducted and that the entire frame assembly is disposed of or recycled and replaced at the end of a typical manufacturer guarantee. As there is presently little consensus on true service lives for architectural products, guarantees are commonly used in published comparative LCAs of window frames, even though they do not represent a realistic portrayal of in-situ circumstance.

Scenario 2 describes a basic maintenance regime in which a typical building manager or owner follows commonly prescribed maintenance practices aimed at reaching a longer life span for the window while maintaining a high level of window performance. Depending on the frame type, maintenance practices may include periodic replacement of damaged or worn components or hardware at regular intervals, and refinishing of the framing material.

Scenario 3 describes a high-maintenance regime in which a building manager or owner follows best practices aimed at extending the lifespan of a high-quality window through regular and frequent maintenance practices. For wood assemblies, this includes regular recoating and refinishing of frames, whilst for aluminium, maintenance includes annual cleaning of the external frames. The use scenario also considers regular replacement and repair of hardware, weather stripping, or sealants as would be expected over time per assembly type to maintain thermal and moisture performance.

All assemblies were modelled using end-of-life disposal scenarios tuned to present construction and demolition waste diversion and recycling rates. Aluminium, steel, paper and plastics received credits associated with materials diverted from the waste stream and recycled at end of life, while wood products received credit from energy recovery associated with incineration. Results of the LCA indicate that the full cradle-to-grave impacts of aluminium window framing are far less than previously reported by other studies. When the true 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 PVCu and 50% less than the best case scenario for aluminium-clad wood. Well maintained wood windows were found to have a 7% lower impact from a carbon perspective than the long-life scenario for aluminium-clad wood framing, and to have a nearly 30% 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.

Well maintained aluminium window framing proved to be the least impactful option across all categories, in large part 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 is clear that material reclamation and recycling at end of life is a significant contributor to reducing the embodied environmental burdens of window framing products.

Towards sustainable cities

The second decade of the twenty first century began with an estimated seven billion people on the planet and the United Nations currently expects the global population to reach 10 billion by 2100. The sustainability challenge shared by all is to provide not only basic needs, but to meet expectations for an improving quality of life. Crucially, this socio-economic progress must be achieved while ensuring the environment remains ecologically and economically viable and able to meet the needs of future generations.

The products of human ingenuity, including the versatile metal aluminium in its many applications, have a vital role to play in successfully addressing this sustainability challenge. Long life, durable, recyclable aluminium applications – which, across their full lifecycle (production, use including maintenance and at end of life), have the potential to save more resources and have a lower environmental impact than alternative materials – in well designed, well specified, well maintained buildings are critical to the 8 billion people who will be living in cities in the year 2100. And perhaps some of those people might still be seeing ‘Sir Giles’ original windows, a century and a half after they were first conceived.

References

1. https://youtu.be/QBTv1kpKZoQ
2. https://youtu.be/9k81OMbsQc