The Future Life Cycle of Intelligent Facades

93 & 93 [1]

ABSTRACT: The UK building industry accounts for approximately 50% of the nation's total energy consumption; generating 33% of landfill waste [1]. Reducing both is paramount for a sustainable future. Disproportionate amounts of energy are currently expended maintaining comfortable internal climates. Intelligent Façades can play a significant role in reducing this energy demand. Intelligent Façades can also be designed to eliminate their construction waste through considering their future Lifecycle. In 'Cradle-to-Cradle' McDonough and Braungart [2] develop James Lovelock's Gaia [3] principles of sustaining existence through closed loop systems with their eco-effective approach to product design. Modelled on natural processes, Eco-Effective design offers a paradigm shift away from the 'be less bad' eco-efficient, by promoting 'waste as food'. Upcycling is the remanufacturing of nutrients, which have fulfilled their primary use, into higher value environmental products. On this premise future Intelligent Façades should be fully upcyclable. At the end of their designed life all components should be efficiently removed and returned to a manufacturer to be reused without wastage. Working alongside façade manufacturer Lindner, architects and Zurich ETH Professors Gramazio & Kohler, and architects 3XN, enabled this research to fully explore the possibilities of an eco-effective design ethos, and devise a set of proposals that could facilitate a global reduction in carbon emissions. Through interpreting and implementing a closed-loop strategy, this paper extends the knowledge of Intelligent Façades day-to-day operation by exploring their future life cycle and eco-effectiveness; i.e. the potential modes of decommissioning and upcycling.

Keywords: Eco-Effective, Life Cycle, Façade, Upcycling, Cradle-to-Cradle

1. INTRODUCTION

'Can future Intelligent Façades be designed to encompass their entire life cycle; from inception and materials through to decommission and upcycling?' To answer this, three areas were considered:

- The importance of the living planet Gaia and how biomimicing natural life cycles is critical for establishing an eco-effective design strategy.
- The relevance of Intelligent Façades and the role they have to play in rescuing Gaia.
- The current state of sustainable design.

The research was conducted in collaboration with façade manufacturer Lindner, who discussed the most prevalent issues and provided a series of case studies to outline the current failings of contemporary design, and architects Gramazio & Kohler in Zurich and 3XN in Copenhagen who specialise in advanced renewable technologies and digital design.

The aim was to pinpoint the key areas currently obstructing wide-scale adoption of sustainable development in the area of façade design and to suggest appropriate strategies for change.

2. CRADLE TO CRADLE: THE LIFEHALT

2.1. The Importance of Lifecycle

James Lovelock proposed the Gaia hypothesis in the early 1970's, suggesting the earth in its entirety 'lives' as a single complex entity forming an intricate interacting system. That system maintains the Earth in an ideal homeostasis for life to flourish. In return, life itself acts as a regulator through actions and evolution. The lack of respect shown Gaia by humanity has disabled her capacity to manage the effects of additional greenhouse gases in the atmosphere, resulting in homeostatic positive feedback causing runaway global warming.

2.2. Eco-Effective

An attempt to counter the destructive tendencies of man was proposed by Michael Braungart and William McDonough in their 2002 text 'Cradle to Cradle'. It offers a paradigm shift away from the 'be less bad' eco-efficient, by promoting an Eco-Effective design strategy where 'waste equals food'. Eco-Effective design models human industry on natural processes through its biomimetic approach to the design of systems. The ideology suggests that all items we make, use and discard, eventually provide nutrition for Industry and Nature alike come the end of their working life. The aspiration is a world in which all human activity nourishes rather than destroys, leaving behind a delightful restorative footprint as opposed to today's degenerative one. In this philosophy human growth is actually viewed positively; the greater the consumption, the higher the abundance of nutrients.

2.3. Contemporary Architectural Barriers

At first glance the notion of increased human consumption appears heretic to those of the established sustainable doctrine, however if the theory is applied it results in a biomimetic design approach that transforms the manufacture and consumption of goods into a regenerative force. Contemporary lifestyles in the developed world are incredibly wasteful, with many usable or edible products being 'Lifehalted' in landfill. In 2009 the UK produced 434million tonnes of waste. 73% of this went to landfill, even though 90% was recoverable and could have be recycled, composted or used to generate energy (This figure must be cut by over two thirds to meet the EU 2020 target). The construction industry contributes a significant proportion of this waste. Hence an eco-effective design strategy for Intelligent Façades is vitally important.

One architectural component where environmental improvements could be sought is the building skin. Contemporary façades from brick built dwellings to high-rise glazed towers offer little more than a barrier between inside and out. This primary function has barely evolved in millennia. The vast majority of buildings still require; heating and/or cooling; a national grid delivering power; materials with high ecological footprints that cannot be reused after demolition. A comprehensive Intelligent Façade design would address these issues and many more.

3. LIFECYCLE: THE DESIGN PARADIGM

3.1. Intelligent Façade Typologies

Despite the many guises of Intelligent Façade, they fall rather comprehensively into three categories; Insolar Façade, Taxonometric Façade, and Responsive Façade. These are defined by the inherent 'intelligence' and what the design is attempting to achieve. The definitions build on one another, meaning one configuration can belong to all three categories, and ideally will do.

An Insolar Façade is a scheme based upon the principles of solar analysis. It is configured in such a way as to minimise or maximise the effects of insolation as required by the building typology.

Taxonometric Façades are those created from a standard kit of parts. The design should allow for many configurations, meaning each scheme using the system can display an individual appearance. The key to the Taxonometric approach is the ability to design for decommission. As the componentry is devised to attach together in a certain sequence, that sequence can be reversed, enabling the façade to be safely and efficiently dismantled. The elements can subsequently be returned to the manufacturer for re-use in another project, or Upcycled to comply with a newer design revision. Lindner's ECO Fassade (Fig.1) has been designed to achieve these criterion. Lindner commissioned PE International to conduct a full Lifecycle analysis upon the ECO Fassade, the details of which are discussed in Section 3.2.

Figure 1: Lindner's Taxonometric Façade

Responsive façades are those that display autonomous control. They exhibit an ability to comprehend and learn from their surroundings, adjusting behaviour accordingly. The building skin is not inert, but transforms dynamically to regulate the internal environment, reducing its power demands. Ideally they include methods for generating energy.

3.2. Life Cycle Assessment

A Life Cycle Assessment (LCA) is a study and appraisal of the environmental effects for any given product. It considers the extraction and creation of raw material, transportation, manufacture, construction, decommissioning, and recycling or waste creation. Extras such as auxiliary material, packaging, water consumption, amount of recycled content, waste treatment, and even radioactive waste should the energy come from a nuclear power station are also included. LCA's don't however take into account the usage or efficiency of the item being evaluated, hence for this report the functional properties of the façade are not incorporated.

PE International developed the LCA software GaBi4. The outcomes are classified into energy and water consumption, waste, and six potential impact categories: global warming, ozone depletion, abiotic, summer smog, acidification, and eutrophication. Whilst incredibly useful the process is complicated, thus the final figures contain large tolerances.

At their behest, PE International analysed Lindner's new Eco Fassade using GaBi4. The results are interesting and summarised below, however they lack context as no others exist for a building façade system. The total energy consumed in the manufacture and production phase of three standard elemental façade types:

- Fully Glazed = 2,480 MJ/m^2
- Fully Clad = 1,950 MJ/m^2
- Part Clad = 3,270 MJ/m^2

The total energy consumed for the façade's remaining Lifecycle, (transportation, on-site construction, and decommissioning), up to the point where the elements are either recycled or discarded:

- Fully Glazed = 1,340 MJ/m^2
- Fully Clad = 1,300 MJ/m^2
- Part Clad = 1,840 MJ/m^2

The Part Glazed configuration consumes the greatest amount of energy due to the increased number of elements. Transport contributes less than 1% of the total, with the average material distance travelled being just 415km. The configuration also comes last in five of the six impact categories, with Fully Clad proving best in five out of the six. Overall, the LCA concluded that two aspects caused the greatest environmental damage:

- Preparation of the anodized aluminium profiles, due to the amount of water and heat required.
- Preparation of the aluminium and steel cladding in the Part Clad and Fully Clad variants.

Whilst initially surprising that the Fully Glazed configuration does not pose the greatest primary threat, construction glass has a series of inherent problems regarding its possible future reuse and Upcycling, discussed further in Section 4.4.

The LCA report states that when Fully Glazed, the Greenhouse Potential is increased by 25% due to the need for insulated glazing. With a reduction in CO_2 emissions critical in the fight against global climate change, it could be argued that this is actually the greatest environmental threat. This reasoning is further strengthened when embodied energies and power sources are considered.

The LCA report also states the Lindner Eco Fassade system is almost 100% recyclable, depending upon the use of a mechanical form of captive glazing gasket. Mechanical capture results in larger mullions, which consumes more aluminium. However, an adhesively glazed system of non-captive glass fixed with Ethylene Propylene Diene Monomer (EPDM) is not at all recyclable due to the inability to separate the glass from the EPDM. Hence, any design decisions must take into account the future reusability of the materials.

To add some perspective to the emission findings, Lindner calculated a comparison. An average car produces 165g CO_2/km, hence if driven for a typical annual amount of 10,000km it releases 1,650kg CO_2. A typical city office façade can be estimated to cover 25storeys of a 25m x 25m floor plan, equalling 10,000m^2. Assuming a fairly low figure based upon the LCA findings of 100kg CO_2/m^2 the façade manufacture emits a substantial 1,000,000kg CO_2.

When considered in such a manner, the importance of the subject matter becomes exceptionally pertinent. Gaining an understanding of these issues and defining methods for reduction is key to developing a successful Eco-Effective design, and why the LCA is an incredibly useful exercise.

4. CONTEMPORARY ARCHITECTURE VS UPCYCLING: INVESTIGATIONS

An Eco-Effective approach offers a solution to the construction industry's waste issues. It would create a true closed loop society where waste was no longer a negative aspect, but a source of nutrients - waste equals food. Lindner conducted two studies in addition to the LCA looking into ways of minimising their ecological footprint.

4.1. Case Study - Harlequin 1

Investigation 1 considered the average recycled content for new material. It came as a response to a query raised by a client. BSkyB, with architects Arup Associates, wanted to design and build Europe's most sustainable broadcasting venue. The aim was for Harlequin 1 in Brentford to achieve BREEAM Excellent and a 35% reduction in carbon footprint when compared to the previous incarnation. To attain this BSkyB insisted on a plethora of energy saving measures including natural ventilation, wind turbines, a biomass fuelled CHP and rainwater harvesting. Lindner were contracted to provide an Insolar façade system. BSkyB prescribed the percentage of recycled content they desired the façade materials to contain, detailed in Table 1:

Table 1: BSkyB's Recycled Material Content Specification for Harlequin 1

Material (external Façades)	Recycled Content (by mass)
Aluminium - Extrusion	44%
Aluminium - Sheet	73%
Glass	10 - 20%
Pre-Cast Concrete	45%
Steel	25 - 90%

Lindner approached the request by determining the greatest percentage of recycled material that could be included for high quality products. Table 2 shows the six most common materials and their average recycled content. The values represent normal, good quality, commercially available products with a recycled content appropriate to the creation of high quality Intelligent Façades.

Table 2: Lindners Recycled Material Content

Material (external Façades)	Recycled Content (by mass)
Aluminium - Extrusion	Not more than 22% Normally 22%
Aluminium - Sheet	12 - 95%
Glass	30%
Steel	Unknown
Insulation	70%
Gaskets, Silicone & EPDM	Nil

BSkyB accepted Lindner's findings following an indepth discussion and analysis of possible methods to increase the percentages. Whilst not being able to do so is disappointing, the fact large corporations and architects such as BSkyB and Arup Associates are beginning to seriously consider these aspects bodes well for future improvements and the eventual adoption of an Eco-Effective design strategy.

An investigation into the future recyclability of Lindner products, conducted in the UK office under the leadership of Technical Director John Libby placed the onus firmly with architects. Libby suggests "designers must gain a fundamental understanding of the manufacturing process and the ecological implications of their design decisions". Two material examples are discussed below, to illustrate Lindner's position.

4.2. Aluminium

Alloys complicate the upcycling of aluminium. When specifying products it is vitally important architects consult their manufacturer, engineer and supplier to determine which alloy most appropriate for the job has the smallest environmental impact. The chosen finishes and coatings applied are equally significant. A standard anodised finish using simple oxidisation is the best option, for it leaves the product fully Upcyclable. Powder coating aluminium involves the use of a polymer such as polyurethane being baked onto the outer surface. This is recyclable but requires the use of a suspected human carcinogen methylene chloride, or energy intensive abrasive blasting, both of which damage the underlying aluminium, causing impurities. Finally, there are numerous 'non-standard' coatings such as high silicon for specific conditions such as corrosive environments. Many of these render the aluminium completely unusable for future reuse, as such the appropriateness of specifying aluminium in these circumstances must be questioned.

4.3. Glass

Glass recycling is widespread and very efficient. Unfortunately, not all glass is the same, and certain architectural glass is difficult to Upcycle. Advancements are continually being made; for example, it is now possible to specify PVC-U windows that can be disassembled at the end of their working lives. The glass is recycled into cullet, the aluminium tracks and beadings can be re-used or Upcycled and the PVC-U frames can be processed into micronised powder ready for a new moulding.

Glazing suffers from attempting to achieve two conflicting goals. Its primary function is to allow natural light in and afford a view out, accompanied by facilitating solar gain. However juxtaposing these aims are minimising glare, heat loss and excessive solar gain. Regrettably, most currently popular solutions have grave environmental implications for future upcycling. Low emissivity (Low-E) coatings are one such case in point. When applied to glass they reflect radiant infrared radiation, hence keeping heat energy on the exterior whilst allowing light in the visible spectrum to pass through. Low-E coatings work wonderfully well at minimising excessive solar heat gains, but have proven extremely problematic for Upcycling. The coatings are usually metallic; titanium, zinc, chromium, silver, tin or even gold, and are applied as a ‘hardcoat’ during the annealing phase of the float glass process. Once administered the coatings cannot be removed, even under extreme temperatures. Consequently any future product created using cullet from Low-E coated glazing, literally falls apart as the metallic elements will not bond. Hence Low-E coating regulate overheating, yet prohibit any future usage of the material.

4.4. Case Study – Microshade

With an eco-effective mentality Low-E coatings would simply not be accepted due to their deficiencies for future Upcycling, alternatives would be sought and developed. In this case a solution has been engineered by Danish firm MicroShade in conjunction with architects 3XN, (Fig.2). A micro perforated stainless steel lamella strip, just 200μm thick is mechanically fixed within standard double or triple glazed units, meaning it is fully recyclable. The micro-perforations are angled to emit a higher percentage of low-level light, whilst reducing high-angle sun penetration by 90%. It can be configured either to appear unnoticeable to the viewer, or to include a patternation. The concept is so successful that Low-E coatings and external solar shading devices are no longer required, resulting in greatly reduced material consumption and economic costs. MicroShade is a good example of an eco-effective product, designed to mitigate an ecological problem whilst not contributing to one.

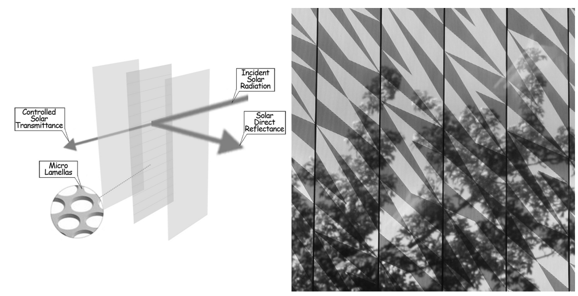

Figure 2: Microshade.

One area requiring a drastic rethink is floor to ceiling glazing. In Britain, any glass located below 800mm from floor height must be laminated safety glass. This is most commonly formed by sandwiching a clear pane of Polyvinyl Butyral Plastic (PVB) between two panes of glass under mild heat and pressure. The glass adheres to the PVB so actively that it does not shatter, remaining intact when broken. PVB is an expensive high performance thermoplastic polymer; its necessity vastly increases glazing costs. PVB itself is fully Upcyclable, however to separate the bonded lamination is such an energy and labour intensive activity it is not economically viable, hence scrapped safety glass heads for landfill. This type of Lifehalt must be addressed in order to reduce the carbon footprint. Simple design choices can instantaneously minimise the issue.

One possible solution for areas where safety glass is required could be the use of biological adhesives. If the glass and shatter proof layer, not necessarily PVB, were bonded in this manner, a biological solvent could harmlessly split the two come the end of their working life. The technology to achieve such a product exists, but is not pursued due to economic constraints. It is areas like these, requiring high capital expenditure but offering long-term financial and ecological incentives, where government funded research should be focused.

4.5. PFI Building Systems

The UK and Australian governments originally developed Private Finance Initiatives (PFI’s) as a means of funding public projects with private capital. In its basic form a PFI can be viewed as a means of reallocating ownership for the functional benefit of those relinquishing control, and long-term financial gain of the recipient. In architecture this could be employed for ecological gains as well. The concept involves the manufacturers of building materials and services not relinquishing responsibility for their product, but effectively leasing them to the client for a contractually agreed lifespan. Throughout a buildings working life the manufacturer maintains and cares for their products, come the end of that life it is the manufacturer’s duty to decommission their property and remove it. The scheme enables new agreements to be formed - either extending the existing contract, or facilitating an upgrade.

A PFI Building Systems initiative (PFIBS) makes commercial and ecological sense. The maintenance provided by manufacturers throughout a products working life ensures a product remains in excellent working condition, reducing building running costs for the client and ensuring building occupiers are never dissatisfied. As the manufacturer is contractually required to repossess the products at a future date, design for decommissions and upcycling becomes an integral part. Consequently wastage and raw material consumption would both significantly decrease. Naturally the concept is not without its detractors who question the realistic possibilities mainly due to the high level of litigation necessary. There are other hurdles that require overcoming before PFIBS’s become a realisable prospect. However, the potential advancements of such an initiative are significant and warrant further consideration.

5. INTELLIGENT FAÇADE FUTURES: THE REALISATION

5.1. Adaptive Attitudes

Radical reform would be required in order to adopt a PFIBS. Such a move could only rationally be realised in a series of small steps, requiring much greater cohesion between the working partners than is currently seen. In order to transform the approach, three concepts must be incorporated into every construction programme. Once each has been addressed a truly eco-effective PFIBS will develop. The three steps are also by no means related solely to architecture and Intelligent Façades, the theories can be applied to almost any design field.

5.2. Removal of Non-Upcyclable Materials

Any product that cannot be broken down into its constituent elements and/or contains materials that cannot be recycled - cannot be upcycled. Such products should not be used. Ideally BREEAM and LEED would perform an LCA on every market product and material. Components that do not comply with stringent rules regarding future usage would be immediately removed from the marketplace, this being enforced through statutory Building Regulations. Whilst this may seem a rather authoritarian way of approaching the subject, developers looking to cut corners and costs will not adhere to voluntary codes or suggested guidelines. As Albert Einstein observed, "No problem can be solved by the same consciousness that created it. We need to see the world anew" [4], therefore to ensure this, ecological design must be stipulated as a ruling. McDonough & Braungart describe this as “Signalling Your Intention” and is part of their ‘Five Guiding Principles’ for establishing eco-effective design. Once this is achieved the consideration of a material's environmental properties will become second nature, rather than the ‘add-on’ it currently is.

5.3. Embracement of Innovative Technologies

Given the need for Upcyclable replacements for all building componentry currently available on the market, a great deal of investment is required up front for this to become a reality. A recent report by the Committee on Climate Change, an independent body established to advise the UK government, called for a substantial increase in the funding available for sustainable technologies and green energy [5]. The report suggested the UK had a unique opportunity during the global economic recession to become a world leader in the research and development of ecological endeavour, indeed not investing would actually prove a false economy.

Whilst the onus is very much on governments to instate legislation and provide research capital to ensure eco-effective design is successful, a large responsibility remains with the architect. Converting to a new environmentally led design system will prove an enormous challenge for many professionals, yet as stated by Brian Anson in 1979, “The Architect who isn't a philanthropist is a philistine” [6]. Numerous firms have made progress; two exemplars being Zurich firm Gramazio & Kohler and Danish 3XN.

5.4. Case Studies – 3XN’s Louisiana Pavilion & Gramazio & Kohler’s Gantenbein Vineyard

The Louisiana Pavilion (Fig.3) exemplifies 3XN’s approach. Based on the closed loop concept, the Pavilion is designed to fulfil its own energy demands, be fully Upcyclable, and totally maintenance free. The structure is built from a bio-composite of natural flax fibres and cork bonded with Ashland’s bio-resin Envirez. Subsequently it is 100% biodegradable. Nano-X's TiO_2 nanoparticles were applied to the substrate, meaning the pavilion is self-cleaning under precipitation as the coating causes the catalytic oxidation of organic contaminants when under direct UV sunlight. Flexcell’s Flexible Photovoltaic panels harness solar radiation for electricity, as do Noliac’s Piezoelectric crystals which deform under the weight of visitor footprints. The power is stored and used to light LED’s at night. The form was originally created by hand using a Möbius strip. It was subsequently parametrically modelled using Grasshopper for Rhino in order for the Engineering and detailed design work to take place.

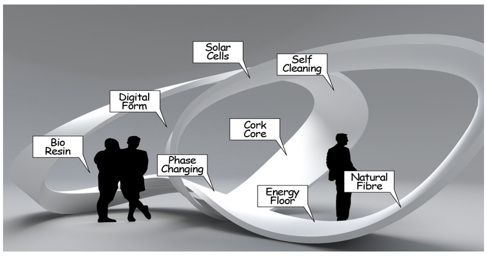

Figure 3: 3XN’s Louisiana Pavilion.

At the Gantenbein Vineyard in Fläsch, Switzerland, Gramazio & Kohler used a robotic production method to lay 20,000 bricks precisely, at the exact interval and angle as prescribed by programmed parameters (Fig 4). The pattern imitates abstract oversized grapes, designed using a generative process replicating grapes falling into a 'basket' - the building volume. Each individual brick was then digitally rotated to form the constantly changing simulated image. A robotic arm is directly driven by the design data, meaning there is no need for drawings. The digital sequence also controls applying the bonding agent. This additive process is intrinsically sustainable, for no waste is ever generated. If a biologically derived adhesive is applied, then the entire façade is also upcyclable as the individual bricks can be separated.

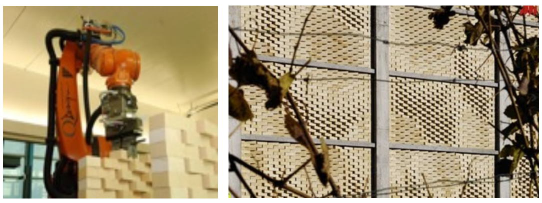

Figure 4: Gantenbein Vineyard by Gramazio & Kohler.

With reference to these two examples of a digitally supported eco-effective design and to previously mentioned research into façade composition, it can be summarised that for an Intelligent Façades to fully satisfy a Cradle-to-Cradle process the following four criteria are critical.

1. The adoption of Private Finance Initiative Building System (PFIBS);
2. The Removal of non-upcyclable materials from the marketplace through building control and regulation.
3. Embracement of Innovative sustainable Technologies.
4. The utilisation of advancements in Computer Aided Design. Adoption of physical methods of representation using digital fabrication.

6. CONCLUSION

This paper considers the possibility of an Intelligent Façade capable of encompassing an entire technological life cycle. From the outset an understanding of Cradle-to-Cradle concepts was imperative, leading to a methodology of eco-effectiveness rather than eco-efficiency. In the present architectural landscape leading examples of façade design are increasingly double skins with integrated building management systems. They justifiably declare their environmental prowess and are indeed advancements in an eco-efficient sense.

The next evolution should now enter an eco-effective era. One inspired by the circular metabolisms of natural ecosystems. Envisage facades analogous to leaves that fall in autumn, to be remoulded and reinvented at the end of their design life. Not recycled, but upcycled to more innovative, higher environmental value products. Facades are changing all around us in any event. Companies continually rebrand and repackage themselves, often materialising into replacement façades. If building frames are considered permanent, then facades are temporary and capable of upgrade. To facilitate this design attitude and government legislation must adapt, in combination with the adoption of innovative materials and constructional techniques that have been described in this study.

If the Cradle-to-Cradle philosophy is to be completed, it could be argued that the eco-effective fabrication and management of facades is inevitable as raw materials become increasingly more difficult to acquire. While manufacturers such as Lindner are now apportioning more resources to the development of these products, any eco-effective method may only succeed if both client and designer meet the challenge with similar economic or ethical foresight.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

[1] DEFRA Municipal Waste Management Survey - England & Wales. London: ONS (2005).

[2] W. McDonough, & M. Braungart, Cradle to Cradle: remaking the way we think things. New York: North Point Press (2002).

[3] J. Lovelock, *The Revenge of Gaia*. London: Puffin Books (2006).

[4] A. Einstein, Only Then Shall We Find Courage. New York: Times Magazine (1946).

[5] CCC, Building a Low Carbon Economy. London: Seacourt (2010).

[6] B. Anson, I'll Fight You for It: Behind the Struggle for Covent Garden (1966–1974). London: Jonathan Cape (1981).