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INTELLIGENT SKINS: AN EMERGING SPECIES

ORIGINS AND FUTURES

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I am very grateful to Peter Wouters and the Organisers of this AVIC Conference for offering me the opportunity to report on some of the work my colleagues and I have been doing on the “Intelligent Facade”, which we see as a central element in the evolution of built form and building fabric to provide environmental control and comfort.

I am aware that my subject may seem at variance with the stated subject area of this Conference, “Market Opportunities for Advanced Ventilation Technology”. As you will see from this brief lecture, my interest lies not so much in ventilation on its own, but in the control of the complete range of environmental characteristics, both internal and external, with the least expenditure of energy possible, as part of an evolving new bioclimatic architecture. However, there is an appropriate complementarity between our objectives, as we seek to incorporate ventilation strategies as one of the many environmental objectives in the complex building envelope.

As we strive to understand how the facade of a building can work to deliver comfort, we are, of course, hoping to reduce significantly our reliance on energy consuming plant. At a recent Seminar at the RIBA on air conditioning, “Cool Space”, a distinguished architectural colleague stated that one of his practice’s objectives in the designing of low energy, “environmental” architecture was to put air conditioning installers out of business. I would not claim that this is my objective for the ventilation industry, but I am sure we all sympathise with the view that we should be making buildings perform much better without reliance on energy consuming plant and services. Whilst our work addresses every aspect of the environment, the subject of ventilation is a key issue. It is my hope that this introduction to this work, and particularly the reference to problems yet to be successfully addressed, will make this lecture a useful contribution to your Conference, and perhaps enable us to build links as we extend the European research programme I refer to later.

THE HISTORICAL CONTEXT

Before I proceed to the two main parts of this lecture, I want to put the subject area into an historical context. The interest we have in addressing the issues of environmental control in buildings is derived from the fact that architects and other design professionals working on buildings have, for a century or more, taken a casual, and even irresponsible, view of the design of buildings, based on the principle that they could be designed comparatively free of the constraints of environmental responsibility, whether the term environment is used to mean the state of the earth and its ecosystem and biosphere, or the characteristics of a building interior. For at least three quarters of the last century, most buildings in the so-called developed world were designed on the basis that the provision of comfort and the delivery of energy and power was primarily the preserve of the services engineer, who could be relied upon to sit quietly in the design team, and solve the problems set by the architects as they designed buildings which paid little regard to the cost of comfort, whether it be cost to the owner, or cost to the planet’s ecosystems. The Modern Movement is curiously devoid of examples of what we would now call environmentally conscious buildings, with notable exceptions such as the sensitive work of Aalto and a few others. This is despite the flourishing of solar architecture before and after the Second World War. Attempts to create environmentally responsible buildings, such as Le Corbusier’s Salvation Army Hostel of 1931, were generally disasters based on poorly understood building physics and appalling budget control. Le Corbusier’s experience of this all glass building in Paris was powerful enough for him to plead with the United Nations not to clad the new UN Building in New York in curtain walling. He failed, of course, and Willis Carrier’s air conditioning saved the day, as it did in countless other irresponsible buildings for the next decade or two.

The Modern Movement, which created much of its agenda in the 1920s and 1930s, evolved in the middle decades of the Century into an inadequate mechanism to deal with the burgeoning technology endemic in the demands of the second half of the century, particularly the demands for energy.

For those of us trained to believe that architecture involves the devising of forms which solves problems of performance as well as of land use, spatial organisation, construction and a resulting visual elegance, the jolt to the system delivered by the 1970s oil crisis and subsequent environmental concerns, was welcome.

For me the present interest in the holistic nature of architectural and environmental theory is the culmination of thirty years work on what is often called "bioclimatic architecture", which has developed particular focus in some of our work over the last 5 years as we have evolved the idea of "The Intelligent Skin".

"The Intelligent Skin", as a term related to architecture, generally evokes a response somewhere between suspicion and derision in most of the professionals to whom we mention it. It may, indeed, be a term which will need to be replaced. However, in terms of the research we have carried out over the last five years we have found it difficult to improve upon, and useful in the way that it borrows terms which enable connections to be made both with biological principles, and with cybernetics.

With this as the context, I would like to use my brief time at this Conference to explain the background to our work, and how it originated, and then explain the work we have been doing in the last few years in consideration of the building as a reactive bioclimatic mechanism. The lecture is thus in two parts, with the first part providing (I hope) the underpinning for the work described in the second part. This underpinning is very important because it sets the proposition in a context of architectural theory, and does not consider it simply as the latest "hi-tech" fad.

BACKGROUND: BIOCLIMATIC ARCHITECTURE

We will all be aware of the current very great interest in sustainable architecture. As awareness has grown of the possible effects of global warming, buildings have been identified as major consumers of energy, and thus major producers of emissions. I will not take up valuable time in this lecture by enunciating the statistics and warnings, which will be well known to all of you.

Whilst I am as concerned as anyone about the need for us to create an architecture which is more careful in its use of energy, and more caring of the environment, my own interest in the subject of bioclimatic architecture goes back well before the early ideas of global nemesis were evolving, and is based on what I believe is a more fundamental foundation for the architecture of the future.

In the late 1960s, whilst working for the large and eminent British firm of Architects, Yorke Rosenberg and Mardall, I produced a document called the "YRM Environmental Design Guide". The idea of this was to act as an office manual advising the Partners, and project architects, on how to discuss the issues which arose as design was progressed with the various firms of mechanical and electrical engineers the office worked with. The document covered lighting, heating, ventilation, cooling, comfort, and the other environmental issues affecting building design. The exercise was useful for me in enabling me to extend my interest in bioclimatic architecture, fostered by an early reading of Victor Olgyay's 1963 book "Design with Climate". By the 1970s, when I became an Associate Partner in the firm, responsible for the design of my own projects, the impact of the so-called "oil crisis" was hitting us financially in the form of inflation and a major downturn in building activity. The publication of "Limits to Growth" in 1972, which summarised work started in 1968, acted as a timely reminder, not only to building designers, of the problems to come in relation to population, resources, energy, pollution, and most of the other aspects of 20th Century human activity. The implications of energy use on climate were pointed out on pages 71-73 of this important book, now 30 years old.

Concerns about energy, ecology, and the impact of human activity on the planet have been with us for a long time, but for me the more interesting aspect of bioclimatic design was reinforced by a reading in the early 1970s of Ian McHarg's wonderful book "Design with Nature" published in 1968. This was a landscape architect's reading of the issues, and agendas, which arise out of consideration of man's interaction with the planet. The Department he founded at the University of Pennsylvania was called the Department of Landscape Architecture and Regional Planning. The embodied concept, that ecology, design, landscape, and regional planning, were interconnected, confirmed my own agenda.

The idea of there being a powerful relationship between buildings and the planet was not an idea created in the 1960s, of course. In a book I requested as a School Music Prize in 1958, one of the founding fathers of the modern movement, Walter Gropius (perhaps a better polemicist than an architect) said that “the greatest responsibility of the planner and the architect ... is the protection and development of our habitat. Man has evolved a mutual relationship with nature on earth, but his power to change its surface has grown so tremendously that this may become a curse instead of a blessing”. Gropius wrote this in the early 1950s, and included it in the summary of his anthology of lectures and writings given at Harvard between 1937 and 1952, in his book “The Scope of Total Architecture”.

Whilst there is an obvious relationship between the celebration and enjoyment of ecological design in McHarg, and the dire warnings in “The Limits to Growth”, the now obvious implications of the two sets of ideas for architecture were not immediately clear to me. It took 15 years of teaching and building to formulate the rather obvious principle that environmentally careful design is not just a social and planetary imperative: it is the basis for an architectural theory.

The fundamental principle of this personal agenda was that architecture could and should be derived as much from the climatic and topographical aspects of a location as from the requirements of a client brief, or a designers ability to manipulate technology. Bioclimatic architecture could be seen as providing the architectural equivalent of bio-diversity, which we know as “local distinctiveness”, as well as ensuring that the evolutionary principles of “design” (as set out in d’Arcy Thompson’s seminal work of 1917, “On Growth and Form”) were properly applied. The exciting potential outcome of considering bioclimatic architecture was the creation of a globally diverse architecture in which “fit” with climate, and the delivery of comfort, was provided at the same time as environmental responsibility, in the creation of new forms of beauty.

In YRM, the office I was in at the time in the 1970s, our first opportunity to test this out was a large teaching hospital in Singapore, which we designed to operate without air-conditioning, and with ventilation as its key formal generator. Working with Steensen and Varming of Copenhagen and Sydney, we derived a form in which orientation, building depth, shading balconies, and completely open elevations, provided the air changes needed both to avoid the build-up of heat, and to ensure the cooling breezes which made patients and staff comfortable. This building was built twenty five years ago, and much of it is still naturally ventilated.

Ironically, work in our own Northern European climate at this time offered fewer opportunities, at least in the architectural practice in which I worked, for bioclimatic architecture. Architects and engineers in practice are sadly restricted to the commissions they obtain, and, at the time, research and speculative design was a rarity in architectural practice. It was this which led me, in the early 1980s, to start work on a commission from the Architectural Press for a new book, to be called “Glass in Architecture”.

My first task was to read every article I could find in every major magazine worldwide, and create a case study list of buildings in which glass was a formative element in the architecture. This rather large task, carried out in so-called “spare” time, led me to discover what appeared to be a breed of building skin which I called at the time “complex multiple skins”.

It was fortunate that the practice I formed with Richard Horden in 1985 won a competition in 1986 which enabled us to design what would have been the largest solar double wall in the world, designed using the Phoenix CFD programme for the first time on a building. Working on the model demonstrated that such a wall, 60m long by 15 storeys high and 3m deep, could deliver a temperature rise of 9 degrees C with upward airflows of 2m/sec, which were so strong that fresh air could be drawn down from the top of the building to serve the solar flue. This replicated the principle of the Occidental Chemical Centre of four years earlier, but with the wall being the south west face of an atrium rather than a double facade. Sadly, after eight years, our Clients, Land Securities, cancelled the project in yet another recession, to build a quite different sort of building.

This experience, and work on the sustainable auditing system for the Earth Centre, a Lottery funded sustainability project in Yorkshire, led me to a more determined effort to understand the importance of sustainable architecture, with a particular thrust in the area of low energy, and I formed a new practice in 1994, the Designers Collaborative, which almost immediately won an award for a project in Athens, known as the Zephyr project, run by the European Union. Our proposal incorporated another multiple facade and, working with Tom Barker and others in Arups, we calculated that we could achieve a resultant temperature of 2 degrees C when the outside temperature was 3 degrees C, assisted significantly by the cross ventilation created by the solar flues drawing air across the occupied 10m deep space from a cool atrium containing a heat sink in the form of a pond.

Meanwhile, the theoretical underpinning of the principles embodied in multiple facades, and my interest in bioclimatics as the basis for architectural theory remained. It was jolted into life by a request to review Martin Pawley's book "Theory and Design in the Second Machine Age", published in 1990. Martin Pawley took the view that technology was getting far too complicated for architects, and we should all just let it roll over us. It is probable that Martin Pawley's tongue was in his cheek, but I wrote an article in the magazine Building Design which was more a rejection of this defeatist view than a review. As a result of this piece, Theo Crosby asked me to lecture on theory at the School of Architecture of which he was Head, the Royal College of Art in London. It was in preparing these lectures in 1992 that I enunciated what I believe is a vital aesthetic principle.

The principle, and its ramifications are simple. Design is considered as a process in which morphological evolution (the design process) produces economical answers to practical propositions. A tree, and the leaf on a tree, represent beautiful examples of this principle. In addressing issues of height, support, spread, energy flow, and reproduction, the tree represents design at its highest level. So too does the human body. Engineers understand this well, and incorporate the principle that the best design is that which produces a desired result with the least possible material. The bridges of Maillart exemplify this. Material and energy are interchangeable, and the fact that energy is invisible does not discount it as a "raw material" which should be conserved. Using the least energy to create and use something has the same value as using the least material. This is an aesthetic concept, and the basis of what is called style in athletics. It is also of course an environmental concept, at least potentially.

I returned to the matter of the facade as a result of an invitation from Bath University in 1995. Professor Richard Frewer in the School of Architecture knew of my interest in the building envelope, and had previously asked me to help his firm Arup Associates in the area of cladding design, specification and procurement. Remembering the database built up in the research carried out for "Glass in Architecture", I proposed that we test the feasibility of what I then called the Intelligent Facade. The proposal was in ten stages, with the first a more intensive Case Study search than my work for "Glass in Architecture" allowed.

The proposal had its origins in two sets of ideas.

The first comes out of research carried out in the early 1980s during the preparation of the Book already referred to, "Glass in Architecture". In a Lecture at the RIBA given in 1985, called "Glass Architecture and the Thinking Skin", the idea of new building skin technologies assisting in the evolution of responsive buildings was set out as an "end-piece" to the lecture. This itself was not new, and had been promoted by architects and engineers for some time, in the UK most notably by Michael Davies and others who had realised the potential of the new glasses and control technologies. Work on the technical content of "Glass in Architecture" undertaken during the late 1980s, made evident the worldwide efforts of designers to develop what were named "complex multiple skins" in my database.

The second origin lay in a "Low Energy" Diploma studio I taught at the Scott Sutherland School of Architecture in the Robert Gordon University in Aberdeen in the early 1990s. With the assistance of such distinguished engineers as Tom Barker of Ove Arup and Partners, and Max Fordham of Max Fordham and Partners, it became quite clear that, whilst buildings could be devised for very low energy in use, varying diurnal and seasonal conditions made the design of purely passive buildings (that is, buildings which could sit, inert, and maintain comfort, day and night, throughout the year), virtually impossible if "zero-environmental-energy" was an objective. The demands made upon the building fabric required the proposition of variable envelopes a prerequisite to the creation of a building with very small provision of environmental services, or perhaps no provision of some of these at all. In the project studies forming the Diploma Programme it was evident that, for example, the thermal transmittance of the building skin should have a different value at different times if stable thermal conditions were to be held inside the building without the importing of energy to drive a heating or cooling system: this requirement for a building to "open up" or "close down" has obvious relationships in the optical actions of the human eye, which we close when we wish to sleep, and the iris of which "stops down" the pupil automatically in bright light. The possible absence of a human operator to produce this action, and the sometimes counter-intuitive nature of the action, suggested that the building ought to be intelligent enough to know what to do in different circumstances in order to maintain its “metabolism” at levels consistent with comfort for its human occupants.

Consideration of these two study programmes provided the basis for the Intelligent Facade Programme devised in 1995. The 10 Stage programme was devised to investigate the feasibility of the Intelligent Facade, this being defined as a facade incorporating variable technology which would amend itself to provide comfort conditions inside the building whatever the external environmental conditions might be, in any particular building location. It was accepted at the outset that this would have to be “proved” to be economically viable, and it was based philosophically on the principle that buildings for much of the 20th century had developed design paradigms such that the morphology and construction of a building was designed to suit one set of functional and aesthetic objectives, often not environmentally driven, only for engineers to be asked to correct the environment by the incorporation of environmental systems, which themselves required large and unnecessary amounts of energy.

Considerations of an “Intelligent Building” thus offered the potential for the development of buildings where variable building fabric, integrated with good “passive” design, could redistribute investment cost from building services into building fabric, and thus reduce energy costs in use, and (it was hoped), total life cycle costing.

Whilst the 10 Stage Programme was intended to include studies of modelling, prototype evaluation, and a variety of other activities, the first appropriate task appeared to be a Case Study Review.

Funding was provided for this first task by the University of Plymouth when I became Head of the School of Architecture in 1996. This enabled Jude Harris to join the research team working on the newly conceived Programme, and we completed the research in 1998. The dissemination of the work, through Conferences and Journal articles, led to a contact from the Ecole Polytechnique Federale de Lausanne who were seeking for a more precise focus to a research programme they were putting together with the Danish Building Research Institute, and this became the programme now known as COST C13 “Glass and the Interactive Building Envelope”.

INTELLIGENT SKINS

I can only hope that the setting out of the background to our current research does not appear to be gratuitous. I have reviewed the background because the idea of the Intelligent Skin is not proposed as a piece of technological exotica. I believe it is part of an approach to architecture which will become increasingly important in the next century, as we integrate conceptual theory and environmental responsibility. The principles are set out in the forthcoming book “Intelligent Skins” to be published later this year, which is the first dissemination of Stage 1 of the research programme carried out in the Plymouth School of Architecture. Since full dissemination is only a few months away, I will spend the remainder of my time providing two examples of our Case Study Review, and explaining how we believe the work should inform future research.

As is appropriate for a Case Study review, we started with a literature search. A resulting database of over 300 examples from across the world included both completed buildings, and unrealised proposals that often resulted from competition entries. A short description of each project was written, describing the intelligent features, and the database also included details of the location, the architect and the year of completion.

It became evident that the term "intelligent building” had been liberally applied to a number of projects that did not necessarily warrant the title. In the context of this study, it was decided that there needed to be an assessment of the specific role of the building envelope in manipulating the passage of energy flows in the form of light, heat, air and sound. About 30 projects were rejected on the grounds of "false intelligence" with no demonstrable features that could be called intelligent other than raised floors for cabling and flexible partitioning systems for easy changes of use. Eventually, as we developed the concept of what “Intelligent Skins” might actually be, we reduced the number down to about 50 projects which demonstrated some form of active control of the facade. The decision to include only completed buildings reduced this list to 37, and subsequent contact with the designers, and the obtaining of further information reduced it further to the final complement of 25.

Study of the buildings themselves created the basis for the development of the definition of “intelligence”. Jude Harris and myself realised that we were looking at a range of concepts, which used a variety of technical systems, controlling the various aspects of the environment, with many of the systems acting upon several environmental characteristics. This led us to develop the idea of the “genetic content” of the intelligent skin, a concept which we found useful, particularly in the context of the evolving biological analogies we were making. We concluded that the study of the skins themselves was tantamount to the identification of a kind of “gene bank” of technical systems and devices, which were forming, rather disjointedly with their many authors, the basis for what might be called a new species of building, active rather than inert, with a much more integrated set of systems and elements than is associated with conventional buildings, with their inert “shell”, and their hard working (and energy consuming) services systems.

The study of examples of building intelligence showed that the facade was performing up to ten different functions, which influenced the passage of energy from both the external environment to the internal environment, and the other way around. These manipulating functions were identified as

the enhancement of daylight (eg light shelves/reflectors);
the maximisation of daylight (eg full-height glazing/atria);
protection from the sun (eg louvres/blinds);
insulation (eg night-time shutters);
ventilation (eg automatic dampers);
the collection of heat (eg solar collectors);
the rejection of heat (eg overhangs/brise soleil);
the attenuation of sound (eg acoustic dampers);
the generation of electricity (eg photovoltaics); and
the exploitation of pressure differentials (eg ventilation chimneys).

Each building was analysed and then described following the same ordering of information, starting with a full identification of the building, its location, and its authors, and finishing with a full bibliography.

The study of built examples enabled us to identify what might be called the “genetic make-up” of the intelligent facade of the future, which could be separated into broad functional groups.

DAYLIGHT CONTROLLERS
Given the low energy efficiency of artificial light, the maximisation of daylight is recognised as one of the key goals in energy design. The case studies display a range of active systems which respond to solar angles, providing optimum positions for motorised light-guiding, reflecting and shading devices. Light transmission can often be varied and adjusted to suit internal demand. Systems operate in response to information provided by sensors that measure outside light and solar intensity, and inside light levels and temperature.

INTELLIGENT LIGHTING
Fundamental in meeting the objective of an effective daylighting strategy is a responsive artificial lighting system, with the ability to deactivate itself in response to adequate natural lighting levels. Many of the case study examples incorporate automatic lighting controls outside the envelope zone, but very much connected to the overall performance objectives of the building skin. Intelligent lighting systems are activated by occupancy sensors and regulated (dimming 100%-0%) in response to sensed internal light levels.

SUN CONTROLLERS
In many cases the renewable resource of the sun can be a principal contributor of energy to a building, both passively and actively. Intelligent systems used to control and modify this valuable resource are incorporated into a number of the case studies. The sun can also be detrimental to internal comfort conditions, and as such it is often necessary to mitigate against its harmful effects (glare). The most common manifestation of solar control is provided by computer-controlled blinds, louvres and other protective shades, all of which can intrinsically be regarded as energy absorbers.

ELECTRICAL GENERATORS
It is now feasible for buildings to strive for electrical autonomy through self-generation. This extends the concept of buildings with “living” capabilities: animals and humans require food for energy, but buildings are

able to harness their energy from renewable sources, most notably the sun. The case studies include examples of electricity generated by photovoltaics, wind turbines, and combined heat and power systems. As the Intelligent Building evolves, it may develop some of the in-built efficiencies of the human body, using every available resource through maximum conservation and recycling.

HEATING AND TEMPERATURE CONTROLLERS

In many of the case study examples, intelligent technologies are employed to minimise the energy burden resulting from the highly serviced elements of heating, ventilation and cooling. Attempts are made to reduce the significant demands for space and water heating through the use of passive solar strategies, provided with more precise motorised control. The sun is also utilised for water heating, with some examples equipped to track the sun automatically for maximum exposure.

VENTILATION CONTROLLERS

Ventilation can be automatically regulated for increased effectiveness and greater occupant control by operable elements of the building fabric, such as retractable roofs, motorised windows and pneumatic dampers. These moving elements can also be automatically closed in unfavourable conditions, such as the inclement actions of wind and rain. Intelligent control mechanisms help to overcome some of the inherent problems faced by natural ventilation, such as air and noise pollution.

Many of the case studies operate a mixed-mode approach to ventilation, and intelligent control systems are utilised to determine when to activate mechanical ventilation. They are programmed to use mechanical ventilation only in extreme conditions, thus maximising natural ventilation and minimising energy usage.

One of the case studies includes examples of self-regulating vents that maintain constant airflow in changing wind speeds. The concept of occupancy dependent lighting has also been applied to ventilation, with local fan units operated only when user presence is detected. A number of the projects include air distribution systems through the building structure. Such integral airflow strategies can be compared with the human circulatory system.

THE DOUBLE SKIN

The double skin is a system involving the addition of a second glazed envelope which can create opportunities for maximising daylight and improving energy performance. There are nine examples of such systems in the case studies. In the summer, the double facade can reduce solar gains as the heat load against the internal skin can be lessened by the ventilated cavity. A natural stack effect often develops in the solar heated cavity, as absorbed solar radiation (the glass, the structure and blinds) is re-radiated. In the winter, the double facade will act as a buffer zone between the building and the outside, minimising heat loss, and improving U-values. Intelligent control mechanisms have been used in most examples to automatically regulate the admittance of air into the cavity, and also closing it up to act as a thermal buffer.

COOLING DEVICES

As well as employing mechanised control of established passive cooling techniques, such as earth heat exchangers, bore-hole water and ground water, many of the case study examples utilise a strategy for computer-controlled night time ventilation for pre-cooling of the thermal mass. Cooled water distribution is optimised in the same way as the heating circuits (which are doubled up in a number of examples).

BUILDING MANAGEMENT SYSTEMS

Essential to the Intelligent Building is the brain, in the form of a Building Management System (BMS). The BMS is the central processing unit, receiving all of the information from the various sensor outstations, and determining the appropriate control response to the actuating elements. An “intelligent” BMS is able to monitor weather changes and control and monitor the operation of both passive and active environmental systems to ensure the most efficient use of energy.

LEARNING ABILITY

The Intelligent Skin, with some of the characteristics of human intelligence, should possess an ability to learn, an ability to adjust and adapt, to cope with new situations, and an ability to anticipate the future (after Jankovic, 1993). With advances in Cognitive Science, buildings are actually acquiring abilities to learn usage patterns and the optimum response to specific climatic conditions. Some of the case study examples utilise current and anticipated weather data to calculate the optimum heating, lighting and shading levels for the building in advance. Neural networks and knowledge-based software algorithms, incorporating fuzzy logic provide some buildings with the ability to learn their energy status and thermal characteristics, and relate prevailing climatic conditions to previous operating strategies.

OCCUPANT CONTROL

It is widely accepted that building occupants should have maximum personal control over their immediate environment, and this can often be more realistically achieved with intelligent technologies. Most current control systems have facilities for manual override, often provided by on-screen control panels and hand-held remote control units. However, there may be occasions when unchecked occupant control will compromise general comfort and energy reduction strategies. In these instances an element of automatic response must prevail, to achieve the most efficient energy performance. In time, users may need to be more explicitly informed of how building systems work so that they have more confidence that a computer might know best. This is conventionally accepted in the operation of simple thermostats.

The review concluded with a description of the operating modes, performance achieved, and energy use, where this could be obtained. Each review when written, was sent to the engineers and architects to ensure their agreement with what had been said.

The analysis which resulted is included in the forthcoming book, and it is inappropriate to go through any of it here. However, it might be useful to note that the buildings themselves extend from the earliest dating from 1981, the Occidental Chemical Centre in Niagara Falls, New York, by Cannon Design, to the most recent we were able to include given the publication deadline, the GSW Building in Berlin by Sauerbruch and Hutton with Arups as engineers, which was completed in September 1999.

The publication of this material is just the start of what we hope will be an ongoing search for facade intelligence, as a part of the overall search for the intelligent building. A Case Study Review is, by its nature, restricted in its ability to propose solutions. Questions also remain unanswered in relation to cost and true effectiveness. Further work has already been carried out with the UK engineers Battle McCarthy, and working with them I have produced the first constituents of a design guide, which is published as a website

www.battlemccarthy.demon.co.uk/research/environmental second skins.

In this research we have carried out comparisons on two theoretical versions of three building shapes: a conventional design with conventional (but very efficient) engineering, and a multiple skin alternative. We co-opted the Quantity Surveyors, Franklin and Andrews, who worked with us on the costs of the various options concerned. This has shown, in theory at any rate, that for typical office buildings the environmental second skin (intelligent or otherwise) can offer a viable alternative to conventional buildings. I believe that further research, using the genetic algorithm, will enable us to explore the potential more deeply.
European Union COST C13 programme “Glass and the Interactive Facade”. Stephen Ledbetter of the CWCT in Bath and I are the UK representatives, and Peter Wouters is also on the Management Committee, which comprises representatives from 16 European Countries, joined by colleagues from the Lawrence Berkeley Laboratories in California.

Most significantly, as I have mentioned in this lecture, the search for better, and intelligent, facades has been embodied in the

The intelligent interactive facade now promises to be an important element in the bioclimatic architecture of the future. Much work has yet to be done on efficacy, and on design principles, but we now have in place a research structure across Europe, which extends into the USA, which should ensure that a significant amount of research proceeds to establish the credentials of this fascinating architectural paradigm.