ROYAL INSTITUTION
ART OF GLASS ARCHITECTURE
1990

IAN RITCHIE

INTRODUCTION

In architecture, glass has for a thousand years been the medium through which light has entered buildings, revealing the spatial art of architecture, while completing the building's protective enclosure of walls and roof against wind, rain and noise while allowing visual contact to be maintained with the outside world.
My lecture focuses on glass as an extraordinary material whose uses and manipulation by man seems inexhaustible from telling stories to making electricity.
The history of architecture has been the story of light as architecture's essential material. Without light there is no architecture. Today we can look back and see how architectural interiors have been created, first by allowing light to penetrate through openings in solid walls, then through small openings in the roof. In the early 20th century, walls could become transparent, and today almost at will, we can make the roof transparent. In this context it is worth recalling the extraordinary achievements of Paxton and others in the mid-19th century, where the entire solidity-opacity associated with buildings was completely removed.
I will describe, using a number of our projects both realised and imagined, how we have used glass as the key architectural material to create not only the visual and spatial experience, but how we have sought to make glass perform in terms of the client's objective and the users of the building.

The lecture will refer to:-
transparency
the control of light and energy - passive & robotic
composing visible light 3-dimensionally,
light memory,
landscape
spherical geometry.
future directions

During the last 30 years there has been a slow, but growing awareness amongst the general public, and the construction industry in particular, of the need for an "earth intelligence" and the important role of building design in physically demonstrating this new direction.

The overall environment of the earth has supplanted the raw energy concerns of two decades ago, and this has broadened industries' areas of research beyond those of renewable energy sources and the energy audit (extraction, processing, supply manufacturing, and cost in use) to now include sustainable materials, zero energy buildings and more environmentally intelligent and responsive facades, not only walls but also roofs. There can be no revolution in the industrialised regions of the world with regard to the way we extract, process & manufacture, distribute and consume materials - i.e. an energy revolution. Only a long campaign will eventually change our habits, of which this conference has a role. We are beginning to use and develop new materials which are less processed by industry (more tactile & saving energy).

History will almost certainly record the limitations of the narrow thinking of air conditioned buildings which developed with high rise building, as our health and the health of the environment become central to our architecture.

Healthy built environments for humans is one important aspect of a continuing biosphere.

1. Transparency

1.1 La Villette façades bioclimatiques 1981-85

2 In 1981 Peter Rice, Martin Francis and I formed RICE FRANCIS RITCHIE in response to the French Government's invitation to work with the architect Adrien Fainsilber on the new Cité des Sciences at La Villette, specifically on the southern facades bioclimatiques and the main entrance hall roof.

3 Adrien Fainsilber's idea for the facades bioclimatiques was that they should be large windows facing onto the proposed park, and should incorporate landscape suggesting a continuation of the park into the museum, and be solar energy collectors contributing to the energy performance of the museum.

As much as we understood the idea, we felt that these three objectives were not obviously mutually compatible.

Landscape suggested obscured views through the windows, certainly from some levels of the museum and the probable need for sophisticated climate control to maintain a satisfactory environment for plants and to limit condensation occurring which would also contradict the desired "window view" to the park.

As solar energy collectors it was important to understand the facades in the context of the overall energy objectives and performance of the very large building, whose dimensions of approximately 80m wide, 250m long and 40m high represented 800,000m3 of air, which would be conditioned. Each of the three facades measured 32m high by 32m wide and 8m deep.

The available surface area behind the glass windows which could receive solar energy was effectively limited to the adjacent museum floor edges, some 100m2 and the 200m2 floor of the facade. Viewed in the context of contributing directly to the museum's energy balance as a whole, this very limited surface would need to be extremely high performing, and there would need to be a substantial and highly efficient thermal energy store and transfer system. Practical issues, cost and differing attitudes resulted in the facades being as energy autonomous as possible, relying as far as practically possible on solar energy alone, thereby acting as energy conservation buffers to the climate controlled museum interior.

4 As windows to the park, we believed that this also implied windows into the museum, and as such transparency was a concept worth developing. It is this concept, and the defining of transparency which became the major objective. Transparency suggests invisible, yet it was clear to us that the structure of the facades would be anything but invisible seen from within the museum. Therefore, it was the clear glass plane which would represent the transparent window, and this suggested a visual relationship to the structure where the structure would appear to support nothing apart from itself.

Of course if this was possible, then the logic of having a structure at all would be questioned. Therefore, how we defined the existence of the transparent surface when viewed from inside and outside would be crucial to the successful realisation of our concept of transparency. We concluded that the mechanical fixing of the glass should lie within the plane of the glass itself, thus visibly identifying the transparent surface. Equally, how people actually look, (the eye scans more easily horizontally) suggested that the facades should have a horizontal transparent emphasis creating clear panoramas. This immediately indicated to us the way we should design the structural wind load systems.

5 In the detailed design engineering of the facades we considered other important ideas such as tension (symbolising "technology with or versus nature"), their didactic role, geometric hierarchy, and scale shift to create complexity and visual richness as component assemblies became smaller, approaching the scale of the human hand.

6 The very particular technical innovation which contributed so much to the successful realisation of the concept of transparency was in the smallest of all the components, the glass suspension assembly which transfers, under normal conditions, the accumulated load of four glass panels to the primary structure. The failure scenario of two adjacent top glass panels breaking simultaneously, together with non-acceptance of the shear load capacity of the vertical silicone joints contributing to stability, meant that the single top suspension glass hole required proof of its capacity to carry in excess of 4000kg. In 1983, this was 7 times greater than the proven experience of international glass industries. This problem was solved, through the machining tolerance of the glass hole and the introduction of a spherical bearing lying in the vertical plane of the glass, which eliminated localised stresses from glass bending under wind load. The final design of this component was flush with the external glass surface and small in scale. The 80's phenomena of built "transparent glass architecture" originates from our project, although most of them have relied on the principle of a simple countersunk fixing through glass carrying much less load. An important characteristic of the facades is that the glass plane is a rigid surface and the supporting structure is behaving dynamically.

2. Glass roofs: as environmental performers

2.1 La Villette roof 1981-85

7 In the initial Cité des Sciences proposals, nearly every 2000m2 bay was to be illuminated by daylight, by means of glass domes, but the evolution of the brief reduced this objective to the main entrance hall alone.

Our concept for lighting the space below was to achieve a degree of control of the quantity and quality of sunlight, which we felt would offer more dynamic to the space as well as the opportunity to create a didactic rooflight. There are two sources of daylight, from the sun and the reflected light of the sky. The basic geometry of a dome is the same as the hemisphere of the sky, and glass domes essentially are simply capturing as much light from the sky. By contrast, our desire to use direct sunlight determined the form of the glass openings in the roof and their structure. Where sky light is constantly radial to the dome, sunlight is parallel but continuously changing its direction to the roof opening.

The architecture of the roof was informed by the location of the escalators, the rectangular geometry of the bay above the entrance hall and the limitations of the existing structural beams which formed the bay's perimeter. Our architectural concept was to provide legible structural and lighting hierarchies.

Structurally, to arrive at the two circular rotating domes, the rectangle was first divided into two approximate squares, then we suspended an octagon within each square from whose eight flying columns a 32 sided polygon supports a circular track on which the motor driven dome rotates on wheels mounted in spring housings. We felt that the lighting should decrease in intensity from the central areas of the domes towards the perimeter of the bay, in much the same way as the structures.

8 To achieve this we designed a translucent, but thermally insulated fabric roof (K: 0.6W/m2/° C). This was composed of two skins of different densities of Teflon coated glass fibre, insulated with 300mm of white spun glass fibres (Fibair) supported on a transparent vapour barrier of fibre reinforced Tedlar film. Between the insulation and the outer structural skin was a ventilated air space. The structural fabric's primary advantage is that it is permanent, and secondly, it allows a certain transmission of light. Overall the structural fabric composite roof transmitted approximately 3% of incident light.

The rotating sunlight domes we designed are shallow truncated cylinders, internally divided by a series of parallel vertical beams, within which were integrated suspended motorised mirrors, made of tensioned mylar film. The central bay of twelve individually controlled mirrors rotated in the vertical plane and tracked laterally, while the mirrors in the adjacent bays only rotated.

9 The central array of mirrors were driven by step motors receiving instructions from a computer. The primary software programmed the rotation of the domes and the movement of the mirrors such that available sunlight would always be reflected perpendicular to the entrance hall floor. Other programmes enabled the central bay of mirrors to focus the sunlight as a beam or diverge the rays at varying angles across the space below.

10 A control console was also placed in the entrance hall to enable visitors to select these different lighting effects. The mirrors could also be parked to allow maximum skylight penetration, as well as with the automatic blinds achieve a high degree of occultation. During darkness the mirrors were available to redirect artificial light beams.

2.2. Eagle Rock House 1981

11 This house in an essay in sequential space, geometry and light shade modulation. The bird metaphor is formally translated through the articulated structure and suspended wings; the tail as a trapped "crystal greenhouse" protecting plants as a counterpoint to the natural landscape; the movement of the motorised external blinds responding to sunlight as a play on ruffling feathers, and the loft energy centre as the bird's head.

12 Originally conceived as a sculpture whose planes, structure and joints were articulated in primary colours and black, this changed to camouflage, using subtle autumn colours and vertical landscape meshes to dissolve the solid vertical planes leaving only transparent openings linking inside to outside.

13 The roof of the two wings, in many ways the principle facade of the house because of the site's topology and large surface area visible from all round, was glazed. This created the opportunity to continue the idea of camouflage by reflecting the sky and surrounding tree foliage create changing light and spatial experiences within the house and to incorporate passive solar energy. The energy system is based on an air to water heat pump capitalising on the higher ambient air temperature within the roof spaces of the wings. The heat is supplied via storage tanks to an air handling unit which then supplies warm air to the space below.

14 The southern external face of the loft is glazed with provision for additional solar energy collection.

The design of the house is much more than just seeking "performance", it is just as concerned with space, structural expression, symbolism, landscape, function, experiment, experience and energy intelligence.

3. Glass facades: architecture + environmental performers

3.1 Fluy House 1976

15 A few years earlier, in the mid-seventies I designed and personally built a passive solar energy heated house in northern France for my girlfriend's parents, who were planning their retirement from farming.

Architecturally it was determined by a very limited budget 300DM/m2, a need to provide a very practical, low maintenance and low running cost dwelling which I, along with my girlfriend could physically build.

16 The concept, "living in a garden beneath a well insulated umbrella" recognised the client's lifelong appreciation of nature's seasons and continual awareness of the weather. All facades were fully glazed and the spatial arrangement of the house was orientated to follow the sun - the bedrooms to the east, day space to the south and evening relaxation to the west. The North area of the house provided a large covered entrance, the garage and workshop.

The core of the house, kitchen, bathroom, utility space and energy centre was on two levels, and was precisely planned to relate to the main spaces and also to concentrate the capital expenditure thus revealing how much internal space could be created from the remaining funds.

The cellar is composed of two spaces: an area within the house for children's play, storage and an oil fired air handling unit, and an area "outside" in the earth but still under the house. This area was divided up to create a wine store where the bottles are laid on earth steps, an area for additional storage and for growing mushrooms and challottes, and an area of rocks for storing solar energy.

17 The steel superstructure of the house, the black plastic coated steel solar panels, facade flashings and glazed doors were all fabricated in Ireland. The structure weighed only 14kg/m2 of floor area, and the glass panels of the facades contributed to the wind bracing of the overall structural frame.

18 The solar panels were placed 25mm behind a number of the vertical glazed bays on the East and West facades functioning best during the early morning and evening as the sun's rays were nearly perpendicular to glass. Into these steel panels was placed 50mm rigid phenolic foam panels, a 15mm air space and a 50mm thick compressed linen flax board provided the internal finish. Air flowed from the house at low level through adjustable louvers up the face of the solar panels and was returned at ceiling level either via the cellar store or directly recycled into the occupied areas of the house by the single fan of the air handling unit.

19 The roof consisted of a semi-stressed ply deck, 200mm fibre glass insulation, vapour barrier and internally finished with pre-painted 6mm, perforated hardboard.

As part of the landscape composition, a solar energy collector (which made use of much unwanted cast iron and steel from the adjacent farm for short term heat storage) was built to provide preheating for the fresh air requirements.

3.2 Stockley Park B8 offices/research building 1990

20 Commissioned in October 1988 with shell and core completion in March 1990 to a 36 week construction programme, the B8 building comprises 82,000 square feet of nett office accommodation arranged on 3 floors to a 9x9 metre construction grid. Two 18x63 metre clear office floor plates flank a central service core and light well providing for single or multi-tenancy occupation. The office spaces are air-conditioned with plant zones located at East/West extremities avoiding roof mounted plant.

21 The building is designed to address a hierarchy of scales so that individual components related proportionally to the whole, resulting in visual harmonies and dynamic interactions. The overall aim was to provide a building of simple visual elegance but rich in detail, combined with environmental performance and economy of construction. It has been described as a "pin-striped business man who is catching a plane".

22 The external skin of the building exploits, and advances technically and in design, the Pilkington double glazed Planar system. It consists of clear and insulated, toughened, ceramic fritted and in some areas low 'e' coated glass panels to a 1385x3000 modules. The panels are fixed to stainless steel pins at four corners which are bolted to extruded aluminium mullions. Careful design of the full height glazing using controlled areas of ceramic fritting, low emissivity coatings and external sunscreens achieve the required thermal and shading environmental performance. The design of the linear horizontal frit pattern allows for clear unobstructed vision areas at seated and standing eye levels and carefully avoids interference patterns ("stereoscopic interference"). It is also used to mask visual clutter common in areas adjacent to the floor zone.

23 Fritting is applied to the inner face of the outer pane and the low 'e' coating on the outer face of the inner pane improves the 'U' value from 2.61 to 1.7W/m2° C. Tests showed that condensation would not occur at the potential cold bridges of the planar screws.

Due to the proximity of a helicopter maintenance depot, the external envelope, including roof, has been acoustically enhanced by increasing the mass of the enclosure. The glass walls are composed of 12mm outer, 16mm air and 6mm inner panes. The roof lights are 15mm outer, 16mm air and 6mm inner.

24 The building grid is extended by a full bay to support large curved perforated stainless steel sunscreens on South, East, and West facades. The patterns of light and shade cast on the glass during the course of the day result in a continually changing modulation of the flat grid of the building face.

25 The 9m wide central lightwell spaces are horizontal glazed (3m wide) using the same glazing system as the main facades which allow zenithal light to flood the internal areas which, together with the lateral light through the main facades, provides high levels of glare free natural daylight throughout the floor spaces.

4. Spherical architecture - all facade, all roofs

4.1 Dubai Pearl of the Gulf 1987

26 The Dubai Pearl and museum was designed in 1987 as the new symbol and landmark at the sea entrance to the city -a symbol to communicate Dubai's emergence as the cultural centre of The Gulf.

The project originated through the Dubai Municipality's approach to the French consulate following Dubai's rejection of all 400 entries in a competition to design a new landmark. In collaboration with the French artist Jean-Louis Lhermite, the concept of a "pearl" as the symbol (a local history of pearl diving) created the opportunity of exploring new spherical geometries and research into doubly curved glass.

27 We sought to establish an 'arabesque" geometry for both the structure and the glazing, and several were produced working with Ensor Holiday and Keith Laws, and developing one in particular which gave a geometric pattern compatible with both a delicate single layer stainless steel structure and the current capacity of the glass industry to produce doubly curved laminated glass panels to acceptable tolerances. Translating the characteristics of beauty of a natural pearl into a glass sphere at a scale two thousand times larger was also a challenge. We concluded that the following essential qualities of a pearl and their physical interpretation for the 20m diameter sphere were:

28 Sphericity : fabrication, construction and thermal movement tolerances.
Translucency : choice of glass, interlayer and surface treatment.
Lustre/depth : choice of glass, thickness, coatings and surface treatment.
Iridescence : optical/surface qualities of the outer glass sheet (day) internal central lighting system performance (night).

It was important that the external aesthetic of the pearl was not compromised by the legibility of the structure during the day, and that, when illuminated internally from a radial light source at night, it did not cast rogue shadows on the inner surface of the glass.

29 To avoid any material, other than glass, visible on the external surface, we designed and tested a prototype countersunk articulated fixing which allowed the external glass surface to be laminated across it. We named it the "phantom" fixing. Prototypes of doubly curved glass pentagon and triangular panels were also made by T W Ide in England and these prototypes shipped to Dubai for client approval.

30 The structure has two layers, the outer stainless steel spherical grid of 45mm tubes following the joint lines between glass panels, and the inner tension stability system of smallest diameter cables connecting major node points, which working together provide all the structural integrity. All the "annular" joints of the outer frame are capable of transmitting movement in all directions such that this outer layer is a rigid structure in its own right. Equally, the completed sphere of glass panels silicone jointed would act as a rigid surface.

31 As with the facades at La Villette, the behaviour of the structure with the glass was crucial and we designed the glass fixing assembly using spring mountings to the structure to overcome construction tolerances, differential thermal movement and structural deformation between the structure and glass sphere.

4.2 The Meridian Planetarium at Greenwich 1989

32 This proposed project, recently granted planning permission is situated on the southern bank of the River Thames near the Royal Naval College, Greenwich.

It is unique in that its projection system will cover almost the entire inner surface of
33 the sphere, (only a narrow band around the equator corresponding to the audience zone is left unprojected). We have named this proposal the "spheriscope". The audience will enter the spheriscope wearing "space slippers" and they can either choose to sit around the perimeter or anywhere on the glass floor. This glass floor initially appears opaque and only when the show is running is the floor switched gently to become transparent. The structure below the floor is being designed integrally with the glass joints to maximise visibility of the lower hemisphere. It is also envisaged that vector video projections of simulated lift off and space flight will also be part of the education programmes.

34 The external skin of the spheriscope set approximately 2m off the surface of the main structure will be white translucent glass incorporating diode arrays to enable light projection of satellite orbits and other imaging arrays to appear on the surface. The glass skins geometry will be based on the longitude/latitude division of the earth's surface. The primary structure of the sphere will be made from 10 to 15mm plate steel to which will be attached the supporting frame for the glass skin externally, and internally the thermal, and acoustic projection surface.

The construction tolerance and thermal behaviour of the monocoque primary structure will be designed such that it will have little effect on the tolerances and precision of either the external glass skin or the internal projection surface.

35 The proximity of the river Thames and London City airport providing long vistas towards the spheriscope will probably make this project a new cultural landmark in London.

4.3 Leipzig Glass Hall: Vaulted Architecture

The glass hall is the principal building through which all visitors to the trade fairs enter, and provides a major space for reception, relaxation, information, informal meeting and formal events. It covers an area 244m long, 79m wide, and is 28m high at its crown. The glazed surface totals about 28,000 sq m (2.8 Hectares). It is to provide a tempered external environment and is linked directly to the exhibition halls through glass bridges.

The architectural objective is to treat the hall as part of a landscaped valley between the two ranks of exhibition halls and conference buildings, and to maintain maximum transparency within this landscape. To this end, the hall is enclosed in frameless glazing using low iron "white" glass (which does not have the characteristic green tint inherent in normal float glass). The structure is kept to a minimum, and covers no more than 15% of the surface. The glass is suspended 500mm below a tubular grid 3.125m square, and glass panels are about 3.1 x 1.55m, made generally of 8 + 8mm, and some 8 +10mm toughened glass, laminated with a 1.5mm pvb interlayer. This is stabilized and supported by primary trusses at 25m centres. Outriggers stabilize the grid shell between these trusses.

The sealing of joints between the glass panels consists of an extruded silicone profile, absorbing expansion, and unstressed applied silicone to complete the seal between the extrusion and the glass edges.

The end walls are structurally independent, and stand as a series of interconnected arch trusses cantilevering from the ground. The glazing consists of 12 mm single toughened low-iron glass.

The internal environment is tempered in summer by very high natural ventilation rates, the internal trees, and by the white reflective fritting on the glass on the south face. In addition it can also be tempered if required by evaporative cooling of the glass by irrigation along the crown, using stored deionised water. Additional environmental cooling comes from 100,000m3 of cooled air overflow from the accommodation buildings within, and from underfloor slab cooling.

The structure, envelope and glass bridges took 10 months to erect.
Not as fast as the Crystal Palace, or as big. Like the Crystal Palace, the Leipzig Glass Hall is demountable, only the composite silicone joints would be destroyed. Working within the context of late twentieth century legislation and safety and security standards it is quite an achievement.

5. Facade as landscape

5.1 National Maritime Museum of the Boat 1984

36 The concept is based on land movement, and sets out to achieve an exciting, active educational centre for the archaeology and reconstruction of boats. Opposite the Naval College at Greenwich, on the north bank of the Thames, it forms a stone amphitheatre to the water edge, thus allowing the River Thames to become the stage, the architecture of Christopher Wren and Inigo Jones to be the stage set and the Royal Greenwich Observatory to be the fly tower.

The result is a discreet, but powerful, architectural statement which expands the use of Island Gardens as a park and visitor attraction.

37 The visitor enters at the garden level into the mid space of the building and is offered the opportunity of a short or long route visit, whilst remaining at the same level.

38 The non-air conditioned internal space is naturally lit through the grass roof and through reflected light entering via the amphitheatre steps. These double glazed linear slots also give the visitor a permanent panorama of the Thames and architecture opposite. The 'clinker' language of stepped construction is taken through from concept to detail.

39 Thus the design treats those who are handicapped as normal visitors and all can enjoy the 3-D shapes of boats around them and witness the reconstruction and launching of boats from within and outside the building.

5.2 Akademie: Herne: Germany 1992

40 We were invited to a limited international competition to design an academy on the site of a former coal pit in Herne in August 1991. The brief stressed the importance of the ecological performance of the building and the treatment of the site as whole.

41 The buildings containing the seminar rooms, administration, residential accommodation and leisure facilities are placed either side along a new landscape route connecting the town centres of Herne and Sodingen through a new woodland park.

The concept of the buildings as a landscaped valley provides the opportunity to draw the public through the academy creating a secure and enjoyable spatial experience. The impact of the buildings on the naturally developing birch woodland is reduced and the landscape and buildings become inseparable.

42 The landscape design limits itself to establishing two ecosystems. the birch wood and the valley with its stream and meadow. The landscape is structured through lines which link it via "vicolli", narrow stair passages to the valley. These lines offer the opportunity for residents and artists to intervene in the landscape.

43 South facing private academy gardens open into landscaped clearings within the wood providing outdoor seminar rooms.

44 The energy concept is structured around the exploitation of Methane produced in the disused shafts for use in a combined heat system. Solar energy is collected in glazed buffer zones of the residential accommodation and the circulation route of the administrative and teaching facilities. Sewage and organic waste is recycled on site, all other waste is separated and used on site where possible.

6. Fragment of a greenhouse

6.1. Terrasson: France 1992

45 A fragment of a greenhouse to express its importance in the development of the European garden. The South storage wall, and the roof as the source of light.

The building is conceived as a reference library and research centre on garden history as well as a public space for exhibitions, conferences, seminars, film shows and other municipal events. It has also been conceived to be a peaceful sheltered space and a tea house in the garden project based on fragments of gardens designed by the landscape designer Kathryn Gustafson.

46 The greenhouse leans symbolically against the hill. Its clear glass flat roof seen tangentially reflects, like a lake, the changing sky and the foliage of the surrounding trees.

The lake of glass will be clear double glazing, fixed to a simple cantilevered beam roof structure in a way that eliminates any visible metal fixings.

The southern facing walls are made of large local stones held in stainless steel mesh "cages" (gabion), thus allowing the building to "breathe" naturally. Internally, this wall is lined by citrus trees.

The construction of the park and of the greenhouse is due to start in 1993.

7. A return to transparency

7.1 Reina Sofia Museum of Modern Art: Madrid 1990

47 Ian Ritchie Architects were invited to design the external circulation towers to the Reina Sofia Museum of Modern Art at a stage when the conversion of the main 18th century building was well advanced to designs by architects J-L Iniguez and A Vasquez. We look three guiding principles:

Minimalism : The reduction of each component to a very simple form. The juxtaposition of these elements to create a rich and legible composition.

Modernity : The visible expression of current and forward-looking attitudes to design and technology.

Performance : In addition to ensuring effective movement for thousands of visitors a day, the aim was to achieve a degree of transparency which has a relationship to the existing building and allows uninterrupted views from inside, both when waiting and, more spectacularly, when riding in the lifts - a pause to make visual contact and re-orientate yourself with the world outside the museum.

48 Given the objectives set out above, and inspired by Picasso's "Guernica" the structure is conceived as a hierarchical composition from large to small scale of vertical and horizontal planes in concrete, steel, stainless steel and glass. The intention is to articulate clearly the functions of each component in this composition thus to provide the legibility of the load-carrying system to visitors.

49 The basic principle of glass support is to separate clearly the external system carrying the weight of glazing and the internal system which restrains the glazing against horizontal wind loads.

Given the demands of a rapid programme, the glazing method uses an established and tested system of glass fixing. The method of suspension is more innovative, but uses simple components designed to allow easy monitoring of quality and rapid manufacture in the quantities required. The glass panels transfer loads from one face to the other at the corners.

50 We provided a detailed analysis of the system and detailed drawings of all components form which Pilkingtons prepared shop drawings for checking. All laser-cut plate profiles were provided full size on film for digitizing, and booklets were provided describing the functioning (thermal, structural performance, etc., and behaviour under accident scenarios) and a recommended method of erection of the system.

We monitored the quality of machining and finishes with submission of samples by Pilkington at appropriate stages in prototyping and production. Key components were load tested to check the engineering of ties and support arms.

51 These two visitor towers, images of modernity, are on the northern side of the museum which meant issued of energy performance and overheating were not crucial design factors.

Where the existing building represents 'gravitas and solidity' the towers represent 'weightlessness and transparency'.

The new satellite towers to the Reina Sofia Museum of Modern Art were completed in October 1990, and Guernica was finally transferred from the Prado to this building earlier this year.

8. Our future architecture

Future Materials

By understanding solar geometry we can recapture the art of carving form and manipulate the surfaces of our buildings with nature's own light pen

Through the development of new facade technologies our own architecture will become more dynamic and less-material, in the sense that transparent structural materials such as glass and diamond films will become the support medium for holograms, transparent integrated circuits, miniaturised lasers and biogenetic coatings offering the possibilities to improve energy efficiency, to create interactive building surfaces to both user and the environment, and release new creative energies in the design and visual pleasure of our buildings. I am interested in nanotechnology - the molecular doping of glass to reduce its crack propagation characteristic while maintaining its glass quality.

In our architecture, understanding the symbiotic relationship of glass and light is crucial. Having explored glass technically over the past decade, our attention is now focussing on light, its energy and colour content.

Natural phenomena such as the firefly, *cold bioluminescent lucifer* - nature's own photonic communicator; mirage; virtual reality, holograms to control, focus and distribute light directly into spaces, or through light pipes (as we proposed in our competition entry for the new School of Architecture in Nancy). As we already pipe water, electrical energy, air, information, and waste through our buildings, it seems inevitable that we will find advantages in piping light efficiently. This should enable us to be more intelligent and creative with architectural spaces and envelopes.

Light is apparently both wave and particle, as demonstrated in the laboratories of Hamamatsu Photonics ('92), where the analysis of photons revealed these behavioural characteristics *simultaneously,* undermining the accepted 'wholeness' of Quantum Theory. There is a long way to go to understand light as a material, and this research "mirrors" the atomic-bonding research of glass with the aim to understand its nature and hence open up new horizons for this ubiquitous material.

Conclusion

Humanity and intelligence have as much to do with the process of decision-making as with the tangible artefacts which result from our application of science, technology and economics.

The need to make evident metaphorical intelligence and humanity in what we design should be indisputable. It is this which drives our design approach.

Real progress for mankind and a real sustainable future for the earth are becoming essentially the same. Architectural and engineering design and construction must deal with its own progress by drawing upon the strong metaphorical stem of the human spirit and earthly values.