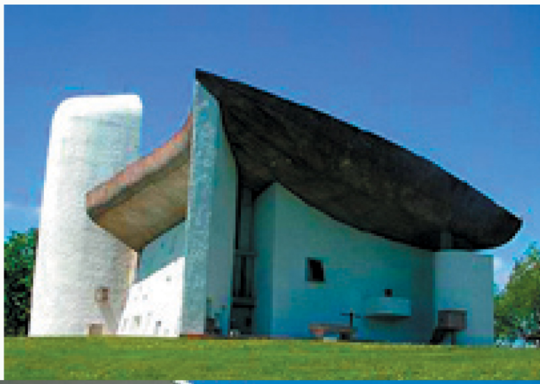

concrete

BHTS 2004 clancy mears

INTRODUCTION

When placed in the hands of talented architects concrete is beautiful. The combination of sand, gravel and lime mixed with water was first successfully exploited by the Romans more than 2000 years ago, but the more recent addition of steel reinforcement has allowed architects to build higher and span further than ever before. The material that starts its life as a soup of grit and rubble has been transformed into some of the most beautiful, elegant and awe inspiring buildings that the world has ever seen. Architects that create the most exquisite concrete buildings exploit the intrinsic qualities of the material, creating daring forms of both structural and sculptural beauty.

The Romans were aware of the tremendous capabilities of concrete when used in compression, and used their Pozzulana brew in arches, vaults, and domes throughout the empire. In the late nineteenth century concrete was given structurally another dimension, when steel reinforcing bars were embedded in the wet mix, giving the final product impressive tensile qualities as well. Concrete construction techniques have evolved to take advantage of the structural capabilities of the material. Architects and artistically minded engineers like Santiago Calatrava, and Pierre Luigi Nervi have designed buildings where the structural qualities of concrete are the main concept of the design, whilst other architects have created elaborate structural systems that are a combination of concrete and other materials. The tensile qualities of reinforced concrete have been expressed in daring designs by architects such as Alvaro Siza and Eero Saarinen. Often due to innovative exploration of the structural capabilities of concrete these buildings have immense elegance and beauty.

Concrete begins its life as a liquid, a sludge that can be cast or applied like plaster – as a screed – to create any conceivable form. Developments in engineering and concrete construction techniques have led to the design of buildings that are in essence concrete sculptures. In fact architects have often claimed to be, or collaborated with artists when designing these sculptural buildings. A natural understanding of light and form are essential to the successful design of a sculptural concrete building, and careful placement of windows and lighting can result in a building that has exquisite sculptural qualities both inside and out. These sculptural concrete buildings often through time gain the status of icons and landmarks, and are the pride and source of income for their surrounding communities. These concrete sculptures appeal to our senses, and their smooth feminine curves and fluid forms are unquestionably things of great beauty.

Although concrete is not the only material that sculptural buildings can be built from, it is one of the best materials for communicating the form of a building due to the monotonous colour and texture of its surface. A concrete building is rarely interpreted as an exploration of materiality; rather one is able to focus entirely on the building's form. Concrete comes in an extremely large module, in fact it is an infinitely large module that is limited only by the continuity of the pour, and disrupted only by expansion joints. The lack of joints in the material makes the resulting concrete form uninterrupted to the viewer, and hence more comprehensible, so the sculptural form of the building is more successfully communicated. The lack of joints means that the conspicuousness of an expansion joint can be used to emphasise or separate volumes. Weather cast or applied; concrete is the ideal material to convey the form of a building.

The great architects understand the effects of weathering and corrosion on concrete and so design their buildings to allow for this. Whether it is a drip groove to prevent water flowing down a wall staining it, or the slight pitch of a concrete roof to prevent water from pooling, the best architects incorporate these allowances seamlessly into their final designs. Architects who ignore the constraints placed on their designs by the elements do so at their own peril, with their buildings leaking, becoming stained, or worse still – compromised structurally. Buildings have been designed with rough brutal concrete facades that become stained and weathered intentionally, adding immensely to the overall effect of the building. Architects must not try to battle against nature – even a material as durable as concrete will eventually submit to the elements, rather they must learn to accept nature and work with it.

The more accomplished sculptural concrete buildings are much more than just an aesthetic delight – they are also incredibly refined functional machines. The fluid patterns that have been created in concrete are not just a result of the initial state of the material, but are also a reflection of the fluid pattern of traffic and circulation systems. People left to their own devices will not walk in a straight line, stop, turn at right angles, then walk straight again – they will instead tend to wander casually, or if hurried will take the most direct route. It therefore makes sense that a building that is a transport hub should allow for direct travel between points, and that a gallery or museum should allow patrons to wander and meander their way through the building. Very few things in nature are straight, orthogonal, or rectangular – but most buildings are. Architects that observe the systems and patterns of nature often create fluid buildings.

Something is beautiful if it is strong and durable, functional and practical, and appeals to our senses. The very nature of concrete means that it is strong and beautiful, and it can easily be built into something functional and practical, but concrete becomes truly beautiful when it appeals to our senses. Weather it be smooth, highly polished and slick, or rough brutal and poetic, in the hands of a true artist concrete can become sculpture. For a building material that is widely regarded as cold and ugly, concrete is a seminal part of some of the world's finest pieces of architecture. It has the ability to be the shell, skeleton, or skin of a building, the roof walls or floor. It is a practical durable material that has the ability to become sensually appealing. Concrete is indeed beautiful.

Concrete is a solid durable material capable of lasting more than a millennium if constructed correctly. The surface of the material will discolour and become covered with lichen and algae if not protected from the elements – but this will not compromise the structural qualities of the material if the reinforcement is sufficiently covered.

. . . .

Notre Dame du Haut at Ronchamp by, Le Corbusier, although constructed nearly 50 years ago is still a contemporary looking building. This in part is due to the revolutionary nature of the architect's design, but more importantly it is due to the remarkable condition of the building, due to the architect's attention to detailing.

The dazzling white walls of Notre Dame Du Haut, in France are protected from all but the most driving rain by an enormous cantilevered roof overhang. Upon careful observation one can notice a groove cast in to the sensually curving concrete roof. This drip groove prevents water from flowing in capillary action along the eaves, and then down the walls. The drip groove is subtle, in fact it often goes undetected, but prevents water from coming in contact with the pure white walls. One may argue that the roof overhang is a purely sculptural feature, but the drip groove is clear evidence of Le Corbusier's consideration of weathering.

The beautifully sculpted gargoyle heaves water from the roof of Notre Dame du Haut, well clear of the walls into a sump. The water - except in the most extreme conditions - does not come into contact with the white walls. If rainwater flows down a wall - especially a light coloured wall - it leaves a stain of residue. A perennially wet wall can become covered in moss and lichen – severely compromising the aesthetic qualities of the design. By preventing water from flowing down the walls of Notre Dame Du Haut, Le Corbusier has maintained the pristine white walls in his design.

The richly textured concrete roof of the Notre Dame du Haut at Ronchamp is left as exposed raw concrete. Le Corbusier's' brutal, poetic statement is here intentionally exposing concrete to weathering. As the concrete ages it weathers and the surface degrades – becoming rougher and more primal, whilst the white walls remain pristine, so the contrast between the two elements is intensified. The sense of the roof being such a massive element is also reinforced by the roof becoming increasingly gnarled with age. The brutally exposed roof of Notre Dame Du Haut is exposed to weathering, however this only adds to the poetic and artistic sentiments expressed by the architect in his design.

The walls of Le Corbusier's' Notre Dame du Haut – if they do become soiled or stained in any way can be easily repainted to return the purity of the white façade. This easily maintainable material is symbolic of the church as a whole – where surfaces that are prone to weathering, deterioration or wear and tear are easily maintained and repaired – however clever design decisions have assured that little maintenance is required on the chapel. Notre Dame du Haut at Ronchamp is easily maintained; therefore it is kept in pristine condition, so the building will continue to look like a recent construction for many years to come.

As a result of Le Corbusier's consideration of the effects of weathering the Notre Dame du Haut at Ronchamp appears to have been recently constructed – in fact the effects of weathering on certain parts of the design emphasise the architectural statements made by the architect.

. . . .

By contrast, Frank Ghery's Guggenheim Museum in Bilbao was built from an enormous budget. This budget was justified on the basis that the materials used on the building required little maintenance, and would last for centuries. The reality is contradictory to the claims made by the architect, with regular maintenance being required to prevent the building from deteriorating.

Ghery's team and the material manufacturers have claimed that the half millimetre thick titanium panels that cover the majority of the Guggenheim Museum in Bilbao are "guaranteed to last one hundred years"[i]. This relatively new material has been used by NASA, but not at a scale, or in the context that Ghery has used it at Bilbao. The effect of the titanium panels was initially magnificent, but less than six years after the building's completion signs of weathering and deterioration are present; leaving one to question the one hundred year guarantee placed on the material.

The titanium panels – at half a millimetre thick – are only marginally thicker than regular kitchen foil. Ghery has detailed the Guggenheim Museum's panels to be folded together, and clipped to the steel framework by these folds. One's first thought is that such a flimsy material could not withstand the sometimes extreme winds in the bay of Bascal – and one would be correct. Extreme winds and local vandals have torn off several panels already, and several other sheets appear to have come unfolded from their neighbouring panels. The apparent flimsiness of the cladding on Frank Ghery's Guggenheim Museum in Bilbao suggests that the architect has not considered the effects that the elements would have on his building.

In less than six years since the building's completion the titanium panels that clad the Guggenheim Museum in Bilbao – particularly those facing the river Nervoin – have become stained, or tarnished by rainwater drizzling down the surface. These unsightly brassy marks are evident even in photographs released by the museum, and Ghery himself for publicity purposes. One doubts that the effects of weathering on the material even crossed the architect's mind, as not only is the titanium flimsy, it is also easily tarnished.

With such obvious degradation to a relatively new building designed by such a prominent architect as Ghery, one entertains the idea that the architect has intended his building to weather, and like a good wine, mature with age. In fact one expects that an architect with such a high reputation like Ghery would have expected such weathering to occur. This illusion, however, is immediately dismissed when the cherry-picker – complete with high pressure hoses, and permanent man power – come into view. A team of cleaners is employed to permanently clean the exterior of the Guggenheim Museum in Bilbao, so evidentially the building was never intended to weather at all.

Despite the one hundred year guarantee placed on the titanium that clads the Guggenheim museum in Bilbao, one is still sceptical about the longevity of the material. The team required to maintain the building, together with the questionable nature of the titanium's rigidity forces one to question the architect's consideration of the effects of weathering on the building.

. . . .

Alvaro Siza's Portuguese Pavilion for Expo '98 in Lisbon is built in a harsh and corrosive environment. Siza has selected his materials carefully and detailed his building well, however less than six years after the building's completion signs of weathering are evident. The Portuguese Pavilion is, however, a building that will mature gracefully.

Perched on the bank of the mouth of the Rio Tejo, close to the Atlantic Ocean, Siza's Portuguese Pavilion is exposed to some of the most hazardous and corrosive conditions a building can endure. Strong winds spray salt water onto the building, and the ever present heat and humidity aid the corrosive process initiated by the salty sea air. Buildings on neighbouring sites built of steel and stainless steel are already beginning to corrode, and the glass on the nearby Vasco De Gama shopping mall needs to be cleaned every other day. In these most testing conditions an architect must pay full attention to weathering.

Siza has chosen to clad the main body of his Portuguese Pavilion in marble – a material that is omnipresent in Lisbon. This resilient igneous rock has been used for construction in Lisbon since antiquity. The age and remarkably good condition of some of the city's buildings is testament to the resilience of the material. The stone – originally white – yellows with age, and although no longer white, the Portuguese Pavilion is still fresh in comparison to the surrounding marble pavement and structures. The Pavilion will continue to yellow and should grow into its surrounds quite eloquently. Siza has used a tried and tested material to construct his Portuguese Pavilion in a harsh marine environment.

The robust orthogonal forms in Siza's Portuguese Pavilion for Expo '98 in Lisbon, suggest a sense of permanence and solidity. This suggestion is supported by the aforementioned materiality of the building which will mature into the site. The concrete element of the building – the immense parabolic suspended roof – no longer has the immaculate just-cast concrete finish it once would have had; it is beginning to weather, becoming rough and a little bit more brutal. This roughness also supports the suggestion of solidity and mass, so although weathering is having an effect on Siza's Portuguese Pavilion, the effect is a positive one.

Siza's careful detailing and material selection has created a building that has, and will weather well. The Portuguese Pavilion is not, however, perfect. The large parabolic roof is pitched slightly towards the river, so the roof water drains toward the city side of the building, simply trickling off the face of the slumped slab onto a drain below.

Any filth and dirt that had built up on the roof is washed off by the rain leaving behind an unsightly build-up of filth and scum on the face of the lowest point of the sagging slab. This is however a relatively minor detail.

The marble and concrete construction of the Portuguese Pavilion for Expo '98 in Lisbon is destined to weather well and mature with age despite the harsh environment it is sited in. The building is testament to the skills of the architect – Alvaro Siza – despite some unsightly scum build up.

. . . .

Concrete, of course, was first used by the Romans more than two thousand years ago. It was their Pozzulana brew, together with their development of arching and vaulting technology that allowed for the creation of vast internal spaces. The Pantheon in Rome is the most impressive example of Roman vaulting.

Although the Romans did not invent the voussior arch they were the first builders to exploit the technology in their buildings. By extending the simple arch, barrel vaults were formed and by rotating the arch they created domes. This technology was assisted by the newly discovered material – concrete, a mixture of sand, rubble and volcanic ash, or Pozzulana – which the Romans used extensively throughout the empire. The Roman's concrete, however, was not reinforced, so although it had tremendous compressive capabilities it had no resistance to tensile forces. Concrete allowed for the construction of buildings on an unprecedented scale.

The Pantheon in Rome is the finest example of Roman vaulting technology using concrete. The vast dome, spanning 43.4 metres is hemispherical and it sits atop a drum whose internal radius and height are identical. The dome is constructed of concrete 1200 mm thick, whilst the drum is over 6 metres thick of solid concrete. The enormous quantities of concrete were required as the concrete is not reinforced. The oculus, a nine metre hole on the summit of the dome, lights the internal space. The Romans successfully exploited the compressional qualities of concrete in the Pantheon, but enormous quantities of the material were required.

By varying the stone used for the aggregate the Romans reduced the mass of certain parts of the Pantheon's dome. In the drum – the area of the building that carries the greatest load – the Romans used Basalt stone – the heaviest and densest stone available. The concrete of the dome on the other hand uses pumice stone – the lightest and frothiest of rocks – as the aggregate to reduce the weight of the structure as much as possible. By varying the type of aggregate used in the concrete, the Romans strengthened certain parts of their building, and reduced the weight of the structure in others.

The Romans used other ingenious techniques in the Pantheon to make the building as structurally efficient as their technology would allow. The inside of the dome is hollowed out by coffering – constructing a series of voids in the areas of the dome where loads are lower to reduce the volume of concrete, and hence the mass of the dome. The drum has a series of "Relieving Arches" embedded in the concrete to disperse loads evenly throughout the drum, and as an attempt to tie the whole structure together. By using these techniques the volume of concrete required to construct the pantheon was reduced.

The fact that the Pantheon still stands today – nearly 1900 years after its construction – is testament to the structural genius of the Romans, and to the durability of concrete. The Pantheon was one of the most daring experiments with concrete ever attempted, and it is a spectacular example of Roman concrete technology.

. . . .

The Pantheon in Rome demonstrates that concrete is a strong and durable material – but it is not immune to weathering. Architects must protect exposed concrete from the elements if they wish to preserve a pristine surface. Le Corbusier shows us that the rough weather beaten surface of unprotected concrete can also have a romantic quality as it does on the underside of the roof of Notre Dame du Haut in Ronchamp.

By comparing the effects of weathering on Siza's Portuguese Pavilion for Expo '98 in Lisbon with those on Ghery's Guggenheim Museum in Bilbao – Two buildings of similar age in similar environments – the durability of concrete becomes evident. The Portuguese Pavilion – although weathering - is maturing gracefully and requiring little maintenance whilst the staff of the Guggenheim Museum must constantly battle the elements to preserve their famed building.

The malleability of concrete means that the forms achievable from the material are limited only by the architects daring and imagination. It is therefore the material of choice for daring imaginative architects to create sculptural buildings from – in fact throughout the world architects have exploited the properties of concrete to produce sculptural masterpieces.

. . . .

Antoni Gaudi's Sagrada Familia has become an icon of the city of Barcelona. As well as being heavily adorned with traditional religious narrative sculpture the temple is decorated with sculptural forms and motifs distinctive to Gaudi. Gaudi's structure in the Sagrada Familia also has an enormously sculptural presence, and it is the pared back concrete additions to the old cathedral that have the most intrinsic sculptural beauty.

Brightly coloured mosaics cover abstract sculptural forms throughout the Sagrada Familia. These anomalies are a feature unique to Gaudi's work, and are present in many of his projects, most notably on the roof of the nearby Casa Mila. These bright abstract forms are most visible adorning the top of the bell towers, and are intended to draw the viewer's eye up, highlighting the verticality of the structure. They also appear frequently across the roof of the church and are visible through from the tower stairwell through the perforations in the structure. Although initially perceived as playful and kitsch, Gaudi took the design of these forms quite seriously from both a religious and artistic perspective.

The different facades of the Sagrada Familia are richly decorated with religious sculptural narrative, in a somewhat traditional manner. Together with " Lorenc Matamala, Gaudi's faithful assistant"[ii] the scenes that would adorn the façades were carefully planned and arranged, with models posing in front of an elaborate system of mirrors for the sculptors to study. These richly decorated facades are precedented to antiquity, but it is this sculptural link with history that gives the Sagrada Familia a sense of familiarity, defining its unique forms as a place of worship.

The unique forms of Antoni Gaudi's Sagrada Familia are primarily a structural response to Gaudi's grand vision, but these forms – even specifically structural elements – have tremendous sculptural integrity. Gaudi's structural elements and forms are heavily informed by nature, with artistic abstractions of trees, shells and bones used prolifically throughout the design giving the built form an enormously organic feel. Gaudi's forms have an intrinsic sculptural quality which although often hidden beneath ornament and decoration is clearly evident in the Sagrada Familia.

It is in the more recent additions to the Sagrada Familia that the sculptural qualities of the forms and structural elements are best conveyed. Staying faithful to Gaudi's initial design, construction of the temple has more recently been of reinforced concrete, and with less ornament and decoration. With an absence of applied decoration the aesthetic sculptural qualities of specific structural elements is immediately apparent, and due to the absence of joints on the surface of the material, one's eye can observe the form of the element more completely, without being drawn along the lines created by junctions in the stone work, elements that are not intended to be part of the form. Concrete is shown to be the more appropriate material for conveying the sculptural qualities of Gaudi's Sagrada Familia.

Antoni Gaudi has created a building that is both adorned with sculpture, and is a sculpture in its own right with the Sagrada Familia. The Building is heavily adorned with both traditional figurative stone sculpture, and bright ceramic clad abstract forms, but the structural elements and form of the building are sculptural in their own right.

Le Corbusier's Notre Dame Du Haut, on a hill above the village of Ronchamp in France is the quintessential sculptural concrete building. With a dynamically curved concrete roof that appears to float above the sweeping walls, an undulating floor and a carefully composed combination of forms, the chapel at Ronchamp is truly a sculptural masterpiece.

The impression of form boards are fossilised in the underside of the grey concrete roof of Notre Dame Du Haut. This harsh brutal materiality coupled with the horizontal band of fenestration at the top of the wall gives the roof the appearance of a floating mass. The evocative curve of the roof – reminiscent of a 16^{th} century sea captain's hat – is the dominating element of the building upon approach. The roof of Le Corbusier's Notre Dame Du Haut has the tactile and aesthetic qualities of a sculpture in its own right, but it is as a component of a larger sculptural composition of the church that the roof's true beauty is best appreciated.

The large sweeping wall of the Notre Dame du Haut at Ronchamp is perforated with stained glass windows, revealing the immense depth of the wall. This massive south facing wall seemably reaches out to greet visitors, and gently directs them to the entry of the building. Covered with white painted concrete the walls sensual curves are caressed by the sunlight on the outside and invigorated by the brilliant hues of light penetrating the stained glass windows. This wall – with its sensual curves, windows proportioned like a De Stijl painting, and playful treatment of light – is a sculpture in its own right, but at Ronchamp it is merely an element in Le Corbusier's larger sculptural composition.

The floor of Le Corbusier's Notre Dame Du Haut in Ronchamp is not – as convention would have it – flat, instead like most other elements in the chapel it is gently curved, however even the most gentle undulations in a floor are immediately apparent. The undulations in the floor surprise the visitor, and hence heighten one's awareness of the curves in the walls and roof. Unlike other buildings with undulating floors – like Fredereich Hundertwasser's KunstHausWein in Vienna – Le Corbusier manages to avoid the realms of the dreadfully kitsch. The sculpted, uneven floor is both a tool to heighten one's awareness of the sculpted surrounds, and an artistic element in its self.

The elements in Le Corbusier's sculptural composition of the Notre Dame du Haut at Ronchamp are separated and married together in a variety of ways, but it is the technique that Le Corbusier uses to separate the volume of the bell tower from the chapel proper that is perhaps the most subtly effective. By disturbing the otherwise uninterrupted surface material of the church wall with two vertical concrete expansion joints Le Corbusier defines the bell tower as a separate element, an entity that would have been an awkward disfigurement to the sculptural form of the building without separation. By isolating the bell tower as an individual form Le Corbusier not only adds a powerful vertical element to his composition, but he also maintains the beautifully sculpted form of the remaining chapel.

The chapel at Ronchamp is a carefully arranged composition of individual sculptural elements that each contribute to Le Corbusier's masterpiece. By contrasting massive with airy, dark with light and rough with smooth Le Corbusier provides immense artistic depth to what is undoubtedly the most sculpturally significant building of its time.

. . . .

Frank Ghery's Guggenheim Museum in Bilbao is a "daring sculptural design that many experts see as a foretaste of architecture in the third millennium."[iii] Composed of contrasting curvaceous titanium and orthogonal limestone elements the museum is designed as a sculpture on the river Nervoin.

The most visually striking feature of Ghery's design is the organic titanium clad forms. These forms previously impossible to calculate and build were designed and fabricated with the extensive use of computer-aided design and manufacturing techniques. These forms are curvaceous yet aggressive, drawing one's gaze around the dazzling forms. Viewed from across the river the forms appear fluid and appear to swamp the Ponte de la Salve. Complex curving planes of titanium meet collide and separate creating lines previously unseen in architecture giving the Guggenheim Museum the energy and dynamism of a Boccioni sculpture. Although fluid and curvaceous, the Guggenheim Museum in Bilbao is certainly not a peaceful sculptural form – its lively lines are full of aggressive energy.

Despite the critical acclaim Ghery's masterpiece has attracted, one cant help but notice that the building appears to have some unresolved junctions, and somewhat clumsy forms. Described by MIT students as having the visual qualities of a crushed soda can, the building has some rather awkward and aesthetically unappealing junctions. Perhaps as part of Ghery's deconstructivist philosophy these clumsy shapes were included to provoke one to question the built form, or perhaps, as one tends to suspect, the design is not as brilliantly resolved as some critics would have us believe.

Whatever the intended effect of the organic titanium clad forms, their presence is emphasised by the inclusion of orthogonal limestone structures. These limestone insertions recede into the surrounds as they are clad in the same stone as the nearby university and the surrounding hard landscaping. The two distinctly different elements contrast with one and other in both materiality and form, each representing the form of the internal gallery they house. Ghery heightens the visual impact of his unique titanium fish scaled forms by juxtaposing them with rectilinear everyday limestone shapes.

It is perhaps in the interior of the Bilbao Guggenheim Museum that the sculptural genius of Frank Ghery is revealed. Due to their monotonous surface the sensually curving plaster walls are appreciated for their sculptural elegance whereas the rich materiality of the building's exterior detracts from the sculptural forms Ghery has created. With similar organic curves to the building's exterior, but with a more pure surface the interior plaster walls have the pared back elegance of a Brancusi work. It is inside the Guggenheim Museum in Bilbao through the white plaster walls that Frank Ghery's sculptural genius is revealed.

Frank Ghery's sculpted titanium forms in his Guggenheim Museum Bilbao are not able to be entirely appreciated due to the complex and unusual nature of the material they are clad in. The forms themselves are in areas awkward and clumsy, and appear unresolved, whilst the white plaster walls inside the building reveal Ghery's true sculptural genius.

. . . .

Alvaro Siza's Portuguese Pavilion in Lisbon for Expo '98 is as much a sculpture as a building. Through unexpected proportioning, materiality and the plastic use of concrete the architect has created a dynamic and evocative work of art who's effect is heightened when viewed together with it's reflection in the Rio Tejo.

Siza has carefully chosen materials that will emphasise the form of his building by not distracting the viewer's attention. The architect uses lightly coloured, everyday materials – concrete and marble – so the viewer is not impressed by rich materials, rather one's attention is focused towards the building's form, so one is able to appreciate the Portuguese Pavilion as a sculpture as well as a building. The use of local Marble gives the building an important link to the city of Lisbon – the capital of the nation that the building represents.

Siza uses unexpected and unusual proportioning techniques in the Portuguese pavilion, especially at either end of the focal concrete roof. The irregular, apparently haphazard placement of the buttresses is not initially apparent, as the buttresses are not entirely visible until one is underneath the vast parabolic roof, at which point one's attention is drawn upwards towards the remarkable roof or through the buttresses to the brightly coloured ceramic tiles between the massive buttresses. The proportioning of the buttresses is best emphasised by the bending of a slit of light that penetrates at the edge of the parabolic roof. This unusual system of proportioning is reminiscent of some of Niemeyer's later works, and gives the Portuguese Pavilion elegance and artistic depth as a piece of sculpture.

Despite the aforementioned devices employed by Siza in the design of the Portuguese Pavilion, it is the suspended parabolic concrete roof that transforms the building into sculptural architecture. This gently curving concrete roof is the focal point of the composition, and it is emphasised by the orthogonal concrete buttresses at either end. The sensually curving roof never meets the supporting buttresses; it is suspended by visible stainless steel cables. The narrow band of light that penetrates this gap makes the roof appear to float weightlessly. This sensually curving, apparently weightless roof contrasts with the surrounding rectilinear heavy forms to give a supremely elegant sculptural composition.

The architect was mindful of the site when designing the Portuguese Pavilion for Expo '98, and deduced that the reflected view of the building in the water as seen from surrounding Expo '98 exhibitions was a vital artistic element. The building viewed together with its reflection appears to be a more complete composition. The strong horizontal ground line serves now as an axis, which the building's silhouette is inverted about. When viewed this way the curve of the concrete roof is even more evocative and powerful.

Alvaro Siza has created a building with delightful sculptural qualities in his Portuguese Pavilion for Expo ’98. The contrast between orthogonal and sensual, and heavy and weightless is the most apparent element, but unique proportioning systems in the buttress give the piece another sculptural dimension. Siza’s sculptural composition becomes complete when viewed together with it’s reflection in the Rio Tejo.

. . . .

The Trans World Airlines (TWA) Terminal at Kennedy international airport in New York, designed by Eero Saarinen is a dynamic piece of sculptural concrete architecture. The curvaceous forms of the exterior are carried through to the interior of the terminal to make a building that was both representative of the then futuristic nature of air travel, and an icon of the TWA company image.

The main passenger terminal consists of four large Ferro-concrete shells that meet at a central point. The “four arched shells of spectacular cut”[iv] are separated physically and visually by long bands of glazing which also allow the interior to be flooded with light. The building takes the form of a soaring bird, with the peak of a shell that marks the building’s entrance being the bird’s metaphorical beak. If in fact the TWA Terminal does represent a bird in flight, it is a delightful abstract sculptural representation that incorporates all of the buildings structural requirements into its organic form. The soaring forms of Saarinen’s TWA Terminal in New York are both sensual and dynamic. Here the architect has handled the concrete forms with a great degree of elegance.

The fluid organic theme of Eero Saarinen’s TWA Terminal have been continued in the building’s interior, with everything from handrails to signs to fixed furniture being designed to suggest speed and flight and to continue the architect’s metaphor. The architect wished for passengers travelling through the terminal to experience an entirely “designed” space. For Saarinen a completely sculpted building was important, with the organic curves of the building’s exterior being no more, or less important than the sculpted forms inside the building. The suggestion of dynamic speed is omnipresent throughout the building.

The TWA terminal was designed by Saarinen in 1952 – at a time when the public saw air travel as a rather futuristic activity. It is therefore appropriate that Saarinen designed the TWA Terminal in a way that – still today – has somewhat futuristic qualities. The sculpted curves and form of the building suggest speed and flight, which is appropriate as the building caters to an airline whose stock and trade is speed and flight. Saarinen's sculpted forms are appropriate as they represent both the services provided by his client and the emotions and excitement felt by the building's users.

The building's dynamic sculptural presence is not only an important abstraction of the client's services or the public's perceptions, it was – and still is – a tool to extend the TWA company profile. A graphic representation of Saarinen's building has been used as a logo by the company, and the building has featured in films, fashion photo shoots and artworks since its completion, generating extraordinary amounts of publicity for the company giving it a crucial advantage over its rivals in a highly competitive market environment. The sculpturally dynamic TWA terminal in New York is a marketing icon and generates priceless publicity for the TWA Corporation.

The TWA Terminal in New York is a sculpturally beautiful building. Its curved concrete shell suggests speed and flight – a metaphor that has been continued inside the building to the smallest detail. Saarinen has designed a building that is both representative of the client's services, and an icon of the company it's self.

. . . .

The Brazilian Congress in Brasilia designed by Oscar Niemeyer is an artistic composition of forms. The juxtaposition of a bowl and a dome atop the plateau of main body of the building create a powerful piece of sculptural architecture that is as much a monument to Brazilian politics as a building to house it.

Niemeyer's composition for the Brazilian Congress consists of a dome to house the Senate and a bowl to house the Chamber of Deputies, both sitting atop a plateau that houses the congressional administration offices. The low concrete dome is visually and structurally sound, and as a building form it is precedented throughout history to Roman times – giving the dome a sense of stability. The bowl, on the other hand, appears to be balancing on a single point, and one feels that even the slightest nudge would cause the bowl to wobble and teeter on its point – the bowl is a decidedly uncertain form. Niemeyer's juxtaposition of two similar forms – one inverted – conveys senses of stability and uncertainty, but the composition is well balanced.

The fact that the bowl and domes have similar forms, albeit inverted, and their proximity to each other assists in conveying the significance of each form. In isolation the dome would disappear into the realms of mediocrity – it is the domes synonymy with the bowl that empowers the form with architectural and sculptural meaning. The bowl does not – as one might perceive – teeter unstably on a point, but has a firm structural connection and wide surface contact with the building below. It is due to the close proximity of a dome of similar shape and size that one's mind extrapolates the form of the House of Deputies chamber to be a bowl. The bowl and dome of Niemeyer's Brazilian Congress are individually unspectacular – it is as an artistic composition that the two elements, together, become a powerful piece of sculptural architecture.

By placing the two forms – the bowl and the dome – atop a podium of Congressional administration offices, Niemeyer appears to be placing his sculptural composition on a pedestal. For Niemeyer this was an appropriate artistic device for communicating the importance of politics for the nation. This podium also suggests an Amazonian pyramid – perhaps a tribute to the acres of jungle that was cleared to make way for Brasilia. By building the bowl and dome atop an orthogonal plateau, Niemeyer defines an area for his composition, as well as communicating the status of the building.

The spaces between the bowl and dome in Niemeyer's composition for the Brazilian Congress were treated with great skill by the architect. An area has been defined by the boundaries of the plateau, and the two forms are proportioned according to these parameters. Much of the internal space of the dome is below podium level. Niemeyer has sunk the dome so that only a percentage of the form is visible – so as not to allow the dome to dominate the composition. Niemeyer was attentive to scale and proportions when designing the Brazilian Congress, and as a result he achieved a beautifully balanced sculptural composition.

The individual forms of Niemeyer's Brazilian Congress are not spectacular, but as an artistic composition the masterpiece is superb. Le Corbusier upon viewing this building remarked "there is invention here"[v], and indeed there is. The invention is in the composition, not in the individual forms. The Brazilian Congress is a spectacular piece of sculptural architecture.

. . . .

The grand Cathedral in Brasilia, also designed by Oscar Niemeyer, is a wonderfully sculptural building, and inside it is a truly breathtaking space. Not only is the building a remarkable piece of sculpture, the form of the self supporting columns is also truly delightful. Niemeyer displays an understanding for light in the "halo" created where the columns meet, and in the rich stained glass windows between his columns.

Niemeyer's Cathedral consists of sixteen massive cantered columns which meet in a ring – or halo – high above the central space of the cathedral, before again diverging and tapering to a point. The halo supports a simple slender steel crucifix to signify the building as a place of Christian worship. The area between the columns is in filled with beautiful vibrantly coloured stained glass. Due to the high proportion of window area, the inside of the cathedral is incredibly light in the day, whilst at night when lit inside the Cathedral emits a magical glow. Almost circular in plan, the cathedral has a strong sense of point symmetry, however the organic nature of the building's forms makes Niemeyer's cathedral in Brasilia sculpturally ingenious.

The column-like elements used by Niemeyer in the Cathedral at Brasilia has an intrinsic sculptural beauty. Niemeyer's obsession with feminine beauty and sensual curves is clearly displayed through these elements which also appear to be somehow aerodynamic. The soft, sexy curves are emphasised by the sharp point at the end of the columns, and by repeating the same form the sculptural beauty becomes more powerful. Elements of natural forms are visible in the column-like features – one can see the suggestion of bones or branches, however the structural role played by these elements is also clearly evident. The sixteen column-like elements each have a powerful organic beauty which when repeated is intensified.

The sixteen aforementioned columns lean inward, resting upon each other creating a structural ring of concrete high above the centre of the Cathedral. This solid structural ring appears from inside the cathedral to float as no light penetrates in this area. The effect of the light and glare and the religious nature of the cathedral give the concrete ring the feel of a halo – a holy presence above the worshippers. From outside one witnesses the columns diverge from this ring of concrete, tapering into a point. Here Niemeyer appears to be making a biblical allusion to Christ's crown of thorns. The area of concrete where the columns come together is an important structural component of the cathedral; however the way in which Niemeyer has treated this area makes it an important sculptural component as well.

The Cathedral at Brasilia by Oscar Niemeyer incorporates stained glass artwork prolifically in the building. The glass from outside appears black and emphasises the white of the concrete enhancing the sculptural form, and the skeletal structural nature of the building. From inside the glass glows with the sunlight behind it and illuminates the vast internal space with vibrant colour. Where the sun is brightest the sun causes the structural column to disappear, further adding to the lightness of the space, and the floating effect of the halo above. When lit inside at night the light pouring through the glass makes the cathedral glow, and the lighting of the structure together with the glow suggests a flower ready to blossom. The stained glass in the Cathedral in Brasilia adds to the sculptural nature of the structure in many different ways depending on lighting.

The cathedral in Brasilia is evidence of the sculptural genius of Oscar Niemeyer. Not only is the overall form of the building sculpturally significant, but the repeated structural element also has intrinsic sculptural qualities. Niemeyer shows his understanding for the effects of light on form, and uses these effects dramatically to add to the sculptural forms of the cathedral.

. . . .

Through examining different sculpturally significant buildings similarities in the different artistic techniques employed by the architects are revealed. Techniques such as material choice, the use of colour, composition and juxtaposition have been used in various ways by different architects to create remarkable buildings that are not only pieces of architecture, but also works of art.

Many sculpturally minded architects emphasise sensual organic forms by juxtaposing them with rigid orthogonal forms. Alvaro Siza's Portuguese Pavilion foe Expo '98 in Lisbon uses heavy rigid marble forms to frame the sensually curving parabolic concrete roof, whilst Frank Ghery's Guggenheim museum in Bilbao sees organic titanium clad forms grow out of orthogonal limestone insertions into the building. Oscar Niemeyer also uses a string rigid horizontal form, and a powerful orthogonal vertical form to centre his plastic sculptural elements in the Brazilian Congress Building. Rigid orthogonal forms do more than just contrast with the plastic sculptural elements, they also remind us of the monotonous nature of the majority of buildings, and help celebrate the uniqueness of the sculptural forms.

Many buildings that successfully exploit the plastic qualities available with concrete could be described as artistic compositions. The most obvious artistic composition for a building is Oscar Niemeyer's Congress building in Brasilia, where strong straight horizontals and verticals are juxtaposed with a dome and a bowl of similar sizes. Siza's Portuguese Pavilion for Expo '98 is also a composition of a long heavy form, a sensually curving parabolic roof and a short rectilinear form – each separated by an apparent void – whilst Le Corbusier's Notre Dame Du Haut at Ronchamp is a composition of individual elements which are all intrinsically sculptural. The designs of Frank Ghery's Guggenheim Museum in Bilbao, Gaudi's Sagrada Familia in

Barcelona, Niemeyer's Congress and Siza's Portuguese Pavilion all include water, and the compositions are completed when the building is viewed together with it's reflection. The careful arrangements of building forms - contrasting or complementing, colliding or separating, and mirroring – create beautiful compositions which define some pieces of architecture as works of art.

Many of the buildings examined used vibrant colours in areas to draw attention to particular areas of the building, or to create different lighting qualities within the building. Gaudi's Sagrada Familia, Le Corbusier's Chapel at Ronchamp, and Niemeyer's Cathedral all employ the use of stained glass. The vivid colours saturate the light pouring into the building with vibrant hues creating a surreal atmosphere – a technique that has been used in church design since antiquity. Both the Sagrada Familia and the Portuguese Pavilion use brightly coloured ceramic tiles to attract attention and emphasise areas of the building. In Ghery's Guggenheim Museum in Bilbao the richness of the material has detracted from the building's sculptural form by overwhelming the viewer. Vibrant colours and rich materials have been used successfully by architects where they are used sparingly to punctuate a building, however when used excessively the material competes with - and sometimes overwhelms – the sculptural form of the building.

Many large sculptural building become icons for the city they are built in, points of pride for pride for cultures or powerful marketing agents for companies. The Sagrada Familia is a symbol for the city of Barcelona, a sign of the Catalan struggle for independence, and a source of pride for the Catalan culture. Eero Saarinen's TWA Terminal on the other hand is a daring abstract representation of flight and a figurehead for the Trans World Airlines Corporation – it is an invaluable marketing tool in a highly competitive market environment. Sometimes intentional, sometimes accidental, evocative sculptural buildings can become icons and emblems for companies, cultures, and cities.

Sculptural buildings are important representations of ideas, philosophies and cultures, and can also be motifs of companies and corporations. They are as important to our society as artworks in galleries, as it is through art and expressive buildings that culture is revealed. Concrete, due to its malleability, strength and surface integrity, is perhaps the best material to construct sculptural buildings from.

Since Roman times people have been aware of the impressive compressional strength of concrete – but the more recent addition of steel reinforcement has given the material another dimension of extraordinary tensile strength. It is because of these qualities that architects designing daring sculptural buildings often use concrete.

. . . .

Pier Luigi Nervi designed four structures for the 1960 Rome Olympics but the Palazzetto dello Sport is the most architecturally interesting and structurally inventive. Nervi used prefabricated pre-stressed concrete elements and conventional reinforced concrete slab technology to create a stadium to span 78 metres and seat five thousand spectators.

The dome covering Pier Luigi Nervi's Palazzetto dello Sport in Rome was constructed using diamond-shaped pre-stressed prefabricated concrete units that were supported on a temporary steel structure whilst a reinforced concrete slab was poured on top binding the elements together. The 1620 diamond shaped prefabricated elements create a textual organic pattern on the underside of the roof which is "created by the webs in which the connecting steel reinforcement was laid"[vi]: The geometric pattern of the prefabricated and reinforced concrete dome transfers the load of the roof to the surrounding stanchions in an ingenious and efficient structural solution.

Nervi's Palazzetto dello Sport is ringed by 36 cantered "Y" shaped concrete stanchions. The elaborate structural system employed by Nervi in the roof saw the roof loads transferred at an angle to the sloping piers so to transfer the load effectively the stanchions were split at the top and positioned at the exact angle that the load was being transferred. These stanchions allow for a curtain glass wall to surround the stadium which makes the roof appear to float. The structural purpose of the stanchions in Nervi's stadium is clear and their form is a response to the way in which the roof load is transferred.

The area at the extremities of the concrete domed roof -in the zone were the load is transferred from the roof to the stanchions – Nervi has used a slightly different structural system to ensure that there were no static problems at this important junction. There is a slight corrugation in this "rim-zone" – the valleys of which is where the load is transferred. The ridge of the corrugation occurs directly above the split in the stanchion and this both allows more light into the stadium and emphasises the unique form of the stanchions. The treatment of the roof's rim zone is both a structural and aesthetic response to design.

The Palazzetto dello Sport in Rome is not only technically excellent – it is also an aesthetically pleasing building that exploits the plastic qualities of concrete. Nervi said "a technically perfect work can be aesthetically expressive, but there does not exist, either in the present or the past, a work of art which is recognised as excellent from an aesthetic point of view, which is not excellent from a technical point of view"[vii], and with the Palazzetto dello Sport Nervi has created a technically perfect, aesthetically pleasing work of art.

Pier Luigi Nervi spent his entire career exploring the possibilities of concrete and concrete construction techniques. The Palazzetto dello Sport –arguably his finest work - uses various concrete construction systems to create a technically excellent, functional and aesthetically appealing work.

.   .   .   .

Le Corbusier's Notre Dame Du Haut in France is an innovative building both technically and aesthetically. Built using aircraft design technology then coated in a membrane of concrete Notre Dame du Haut was a welcome change from Le Corbusier's dreary rationalist concrete buildings using then everyday concrete construction techniques.

The apparently massive concrete walls that protect the inner sanctum of the chapel are in fact hollow – as one discovers upon knocking. Using aircraft design technology Le Corbusier designed the walls to be constructed of a steel frame. The frame - then covered in mesh – was sprayed in concrete giving the walls the texture of American Stucco. This rough texture, however, affirms one's initial perception that the walls are solid. The walls depth also conceals the roof supports as the wall itself bears no load. Le Corbusier designed an efficient construction technique using existing technology from another industry.

The dramatic concrete roof - which is visually the most prominent feature of Notre Dame du Haut at Ronchamp – is by all observations and expectations a mass of solid concrete. This however is a misconception as the roof is a thin concrete shell supported on slender steel columns set within the walls. The impressions of the form boards is fossilised on the underside of the roof – clearly visible in the raw brutal concrete surface. The sweeping curve of the concrete roof acts as a sounding board for hymns sung inside the church. The deceptively lightweight roof is supported using an ingenious but simple system of slender steel columns.

The concave roof of Notre Dame du Haut in Ronchamp acts as an enormous box gutter – collecting falling rain in its concave surface and expelling the water via a gargoyle whose "shape is reminiscent of the nostrils of a horse"[viii]. The gargoyle heaves the water clear of the walls into a vast sump from where the water dissipates into the earth. Although not an entirely unique or unprecedented technique of dealing with rainwater, Le Corbusier's elegant design uses the sculptural shape of the roof – with its aforementioned properties – as the water collector and remover.

Le Corbusier invents structural systems, perfects existing systems, and adapts techniques from other design industries in his design for Notre Dame Du Haut at Ronchamp. The structural techniques employed by Le Corbusier allow him to achieve his desired aesthetic and sculptural effect. The imposing feel of the massive roof floating would not be possible – for example – without the horizontal slit windows at the top of the wall which are made possible due to the columns set within the wall that support the roof. The chapel at Ronchamp is a magnificent example of sculptural architecture which is only made possible by the structural techniques employed by the architect.

The Chapel at Ronchamp is one of the finest examples of sculptural architecture of the 20th century, but it is also technically brilliant. The apparently massive concrete roof is actually lightweight, and the thick walls are hollow, but due to Le Corbusier's careful surface treatment of concrete in both cases our initial perceptions are strengthened.

. . . .

Antoni Gaudi's Sagrada Familia in Barcelona is a structural masterpiece based on mathematical geometric forms. The structural purity is still visible beneath the thick growth of sculpture that infests the cathedral.

The Sagrada Familia was designed based on the mathematical geometry of the hyperbolic parabolic and the hyperboloid. The geometry of the building was perfected using a series of furnacular models devised by Gaudi – a system in which an inverted model of the structure was made using chains and weights – then photographed and analysed. One can clearly see the effects of these models in an inverted section of the cathedral. Already complex enough in two dimensions the geometry is used again in the third. The complex mathematical purity of the system is clearly visible in the cathedral as built thus far, despite the hoards of figurative sculpture coating the building.

As well as using Furnacular models to devise the structure of the Sagrada Familia, Gaudi also made a plethora of plaster models in which even finite details of ornament can be seen. These models – in white – appear even more anatomical and skeletal than the final building. The tilted "tree columns" inside the Sagrada Familia especially have the feel of bones and tendons. These models – largely destroyed in the Spanish Civil War – have been remade or repaired and are used in addition to working drawings in the continuing construction of the cathedral. Gaudi used models both to design and communicate the design of the structure of the Sagrada Familia.

Although designed by Gaudi as a stone building the structural system used to construct the Sagrada Familia would be more suited to concrete construction technology. Although curved surfaces are omnipresent in the temple, flat form boards could be used due to the hyperbolic parabolic geometry – a technique perfected by Felix Candela who used similar geometries in his structures in Central and South America. In fact construction continues using reinforced concrete and elaborate Glass Reinforced Plastic moulds to create the ornate details designed by Gaudi in the concrete. As well as the sculptural and aesthetic advantages of concrete it would also be cheaper, lighter and quicker to have constructed the Sagrada Familia from concrete.

Constructed in a style dubbed "Mediterranean Gothic" - by Gaudi – the Sagrada Familia due to its adornment with sculpture, materiality, and most importantly concentration on structure is indeed reminiscent of the great Gothic cathedrals, but it is vastly different from the Gothic Revivalism popular at the time of its design. The Sagrada Familiar's tall belfries are tied together with pedestrian bridges – which brace the elements against each other without detracting from the slenderness of their form. Gaudi uses many subtle techniques like this to make his temple structurally sound without having to resort to the use of flying buttresses. Nevertheless, the Sagrada Familia is essentially Gothic.

Using an elaborate system of furnacular and plaster models, Antoni Gaudi developed a complex but functional structural system for the Sagrada Familia using mathematical geometry. The skeletal resulting structure would be more suited to reinforced concrete construction using today's techniques, and the structure would be best displayed, without the ornamental blemishes that cover the temple.

. . . .

The Satolas TGV Station outside Lyon, France, is a dramatic sculptural building which links Lyon airport with a TGV train station. The high tech approach the architect – Santiago Calatrava – took when designing the TGV Station is a reflection of the technology in the TGV trains, and the aircraft. This technology is expressed in the building’s structure.

The Satolas TGV Station is dominated by a pair of swooping arches which suggest speed and flight. The arches sprung from a common point at one end are most importantly a sculptural expression and focal point of the building, but are also structurally efficient elements that span the entire length and width of the central terminal. Built of carefully cast concrete the edges of the formwork panels are clearly visible in the textured concrete surface of the arches. The arch – a simple structural element precedented to Roman times – is the underpinning element of Calatrava’s TGV Station, and the element about which the building’s design is based.

Beneath the two dominating concrete arches in Calatrava’s Satolas TGV Station is another pair of arches which share common radii with the said dominating arches. It is the profile of these secondary arches about which the main body of the terminal extrudes. These two arches are connected by slender steel spoke-like elements which tie the arch securely to the ground, whilst allowing for vast clearstory windows to light the main terminal. The spoke-like elements visually and physically link the main arches with the secondary arches supporting the fenestration and anchoring the roof.

The two aforementioned dominating arches are sprung from a common point but separated at the other end – giving the main structure three points of contact with the earth. The arches are further stabilised by the said spoke like elements, but it is the membrane between the arches to which the lateral stabilisation of the system can be accredited. This membrane is a web of steel trusses and bracing elements clad in sheet metal and glass. The swooping roof – the visually dominant element of the Satolas TGV station is structurally sound. It is static due to being in contact with the earth at three points, and with a rigid membrane joining the two main elements.

Structure is the main concern for Calatrava in his design for the Satolas TGV Station. It is the building's structure that gives it dynamism and sculptural integrity. Calatrava has therefore emphasised the focal structural arches by springing wings off the side of them. These steel framed wings cantilever out over the main body of the building, and shelter the vast clearstory windows from harsh sun penetration – but are predominately aesthetic elements. Calatrava emphasises the structural elements in his design making the building more dynamic and sculptural.

The swooping roof of Santiago Calatrava's Satolas TGV Station in Lyon is reminiscent of Saarinen's TWA terminal – however Calatrava has used concrete arches combined with steel and glass in his structure instead of concrete shells. The structure dominates the aesthetics of the building, but is also technically excellent – with concrete, steel and glass married together superbly.

. . . .

Alvaro Siza's Portuguese Pavilion for Expo '98 in Lisbon is a brilliant example of an artistic composition of architectural elements. It is also structurally ingenious. The main focal point of the building – the sagging roof – is supported by a system of cables and buttresses that are detailed superbly endowing the building with sculptural elegance.

Massive planes of reinforced concrete hold the concrete roof in tension in Siza's design for the Portuguese Pavilion. These rectangular vertical slabs of concrete are braced by less substantial concrete walls which restrain the buttresses vertically. The buttresses are placed at irregular intervals for reasons of composition – not structure – and also help to define the space under the roof. The enormous size of the concrete buttresses is a reflection of the substantial sheer force applied to them by the cables which support the roof. The reinforced concrete buttresses prevent the roof from sagging further – transferring the lateral force of the roof to the ground.

The massive parabolic concrete roof in Alvaro Siza's Portuguese Pavilion for Expo '98 in Lisbon is supported by a series of stainless steel cables. These cables – at 600mm centres – span the entire 60 metres between the buttresses supporting the enormous load of nearly 700 cubic metres of concrete. The cables are exposed for 900mm between the edge of the slab and the buttresses – where light flows through giving the impression that the slab is floating and unsupported. The shape of the curved roof is defined by the natural slump of the cables. The impressive tensile strength of stainless steel is displayed in the parabolic roof of Siza's Portuguese Pavilion.

A 200mm concrete slab was formed around the aforementioned stainless steel cables to create the famous sagging parabolic concrete roof of the Portuguese Pavilion for Expo '98 in Lisbon. The outline of the plywood sheeting on the underside of the slab bears witness to the concrete casting process. One's initial perception is that the reinforced concrete slab is spanning the entire 60mx58m unsupported – this however is not correct – the slab actually only spans the negligible distance between the steel cables. The roof which is slightly pitched to remove rainwater is structurally ingenious and is the key part of Siza's composition.

The main body of Siza's Portuguese pavilion for Expo '98 in Lisbon is although beautifully detailed quite unremarkable in comparison to the parabolic roof – thus more conventional reinforced concrete and partition wall construction technology has been used to build this more conventional and restrained part of the building. This part of the building is clad in local marble, and it is this and the regular orthogonal form of the building that help it to recede into the surrounds – thereby emphasising the more significant areas of the building. More elaborate and expensive construction techniques have been used to construct the parabolic concrete roof of the Portuguese Pavilion whilst the main body of the building is built using conventional construction techniques.

The Portuguese Pavilion for Expo '98 was built using inventive methods. The ingenious structural design – by Siza and his engineer – has created an elegant sculptural building. The use of reinforced concrete in tension at this scale is rare, but Siza managed it competently to create a remarkable building.

. . . .

Concrete Construction is an extremely old technology. The addition of steel reinforcement meant that more lightweight structures were achievable. 20th century inventors like Pier Luigi Nervi and Le Corbusier added a further advantage to concrete with the popularisation of pre-cast prefabricated elements. Pier Luigi Nervi's Palazzetto dello Sport is perhaps the first prefabricated concrete building to depart from the industrial aesthetic.

By examining Gaudi's Sagrada Familia one sees the time and cost advantages of using concrete instead of more traditional materials like stone. Other architects like Calatrava and Siza have combined steel and concrete to create structures with intrinsic sculptural beauty.

It is not only the malleability and structural strength of concrete that make it an exceptional material for the construction of buildings with sculptural forms – the inherent aesthetic properties also add to the suitability of concrete as a building material. The monotonous colour and texture of concrete serve to enhance the forms of a building by allowing the viewer's thoughts to concentrate entirely on the building's form.

Buildings with a sculptural form can be built using a variety of construction techniques and finished with various materials – but extravagant materiality often becomes the key visual experience – detracting from the form of the building.

. . . .

Frank Ghery's Guggenheim museum in Bilbao is a spectacular sculptural building that combines fluid titanium clad organic forms with solid limestone blocks of a more conventional orthogonal form. Conceived as a huge sculpture wedged between the banks of the river Nervoin and the grim town centre of the Basque stronghold of

Bilbao – the inclusion of the heavier more traditional limestone elements serves to enhance the effect of the lightweight experimental titanium forms.

Ghery uses the half millimetre thick titanium panels “to give the surface greater tactility and beauty”[ix] – these panels are often referred to as “fish scales” and assist to further one of the architect’s favourite metaphors of a leaping fish that he has already explored in other buildings and sculpture.

The geometric limestone insertions in the building are designed to recede into the backdrop of the city and are in fact clad in the same material as the surrounding hard landscaping and nearby university of Deusto. The primary function of these forms is to enhance – by contrast – the fluidity of the titanium parts.

One wonders if Ghery’s main exploration through the Guggenheim Bilbao is one of form or materiality. The unprecedented forms and the unusual qualities of the titanium sometimes compete for visual presence. The titanium’s hue changes colour with varying weather conditions – and even from a distance the shimmer of an individual titanium panel is clearly evident.

The Titanium panels used to clad the Guggenheim Museum in Bilbao have a somewhat hologramatic quality. As well as being highly reflective as an individual unit the panels reflect each other – resulting in a rather dizzying experience for the viewer. The panels also change colour with the weather – appearing as anything from a dazzling platinum white in bright sunshine to a mellow golden glow in rainy or overcast conditions. If Ghery had chosen to use concrete as a surface material there would have been no mistaking that the Guggenheim was an exploration of form – as the building’s surface would be monotonous both in colour and in texture. This would serve to enhance the sensual sculptural forms Ghery has created.

The question of a monotonous surface material being used to emphasise a form is answered by Ghery himself inside the Guggenheim. The sensual sculptural plaster walls inside the museum are pure white and have a consistent surface texture. These forms – for me – are far more appealing than any of the scaley external surfaces of the building. It is said that these plaster walls "suggest the moulded ribbing of a drawing by Willem de Kooning"[x], and indeed these walls have the sensual artistic qualities of a work by Brancusi, or Arp.

The Bilbao Guggenheim is undoubtedly a master piece in sculpturally conceived architecture. One, however, must question the feasibility of the astronomically expensive method used to clad the building – especially when the longevity and aesthetic appeal of the material are questionable.

. . . .

Le Corbusier's Notre Dame Du Haut is a delightful exploration of the plastic qualities of concrete. This chapel is an important pilgrimage site and was opened in 1955 to replace the town's previous chapel – on the same site – that was destroyed in World War II.

The white walls of Notre Dame du Haut are painted concrete. The concrete – due to the spray-on application process – has a particularly coarse texture, but this consistent texture and colour – and lack of expansion joints – allows one to fully appreciate the sculptural beauty of the design. Where expansion joints are included in the external walls they are used to enhance vertical volumes and to distinguish one form from another. These white walls convey a certain lightness and fragility despite their substantial depth.

The underside of the roof of Notre Dame du Haut – which is the most visually prominent feature when approaching the building – is rather obviously concrete that has been formed by timber slats. The rugged texture and dreary colour of this concrete roof contrasts delightfully with the purity of the surrounding white walls. The fenestration separating the roof from the walls means this contrast is experienced both internally and externally.

Notre Dame du Haut was for Le Corbusier a departure from the prefabricated preassembled architecture he had previously pioneered. It was also a departure from the somewhat bland industrial aesthetic inherent in buildings produced on a production line. The Prefabricated architecture - inspired by the automobile industry – was instead replaced with a new technology for construction – inspired by the aeroplane industry. This steel-framed concrete architecture was relatively cost effective and allowed for unique forms to be created. By again pioneering new technology Le Corbusier was able to create one of the world's finest concrete buildings.

In Notre Dame du Haut at Ronchamp Le Corbusier uses the same material – concrete – for the roof and walls, but achieves very different surface qualities from the material due to the differing processes of construction and application. The white-painted spray-applied concrete walls express the building's sculptural form and also reveal a certain lightness and delicacy in the structure, whilst the rough off-form concrete creates a sense of mass overhead, and the brutal primitive nature of the surface contrasts with the pristine white walls. Le Corbusier's Notre Dame Du Haut at Ronchamp is nearly 50 years old, but appears to be a quite recent building. This is largely due to the materials from which the architect chose to construct the chapel.

Le Corbusier used materials that best suit his exploration of form and creates the ambience he required for Notre Dame du Haut. Through the inventive treatment of concrete and fenestration he has created a true masterpiece, and set the precedent for modernist concrete design.

. . . .

Alvaro Siza's Portuguese Pavilion for Expo '98 in Lisbon is a building of remarkable eloquence. Undoubtedly the most spectacular aspect of this building is the wafer thin parabolic concrete roof suspended on stainless steel cables. The main pavilion, however, is a fine example of careful detailing in marble and ceramic tile. The Portuguese pavilion is built on a prominent site on the banks of the Rio Tejo and is the best of many magnificent examples of architecture on the Expo '98 site.

Using a system of high tensile stainless steel cables Siza managed to suspend a concrete slab over a distance of 60 meters. The curving roof plane heightens the view to the water, but both its form and materiality have an abstract ambiguous quality. The design of the roof was driven by the necessity to shelter large crowds in an outdoor area. The majority of the Portuguese Pavilion is clad in marble panelling. Marble is used prolifically throughout the city of Lisbon as corbel stones in most public places – including the Expo '98 site – and in most important buildings in the city. The use of marble panelling gives the building a strong sense of regionalism, and as the marble is a similar colour and tone to the concrete the two distinctive sections sit together harmoniously, creating a marriage between the rectilinear marble pavilion and the parabolic curve of the concrete roof.

Siza uses brightly coloured ceramic tiles in between the massive buttress supports. Colour is used here in such a way that it highlights the form and eloquence of the buttress – though it is not as eye-catching as one might expect. The ceramic tiles are positioned in such a way that one must be underneath the parabolic roof before they come into view. Siza's carefully considered use of ceramic tiles serves to draw one's eye to the main structural forms of the building.

Siza's choice of materials for the Portuguese Pavilion for Expo '98 gives the building a largely homogenous quality, but the materials were obviously chosen for the task they had to perform. The main body of the building is clad in the same local marble that is used throughout the city, the parabolic concrete roof provides a sense of suspended mass and becomes the sculptural focal point, and the ceramic tiles are used to emphasise the structural forms of the building.

. . . .

The soaring Sagrada Familia in Barcelona is a work widely attributed to and predominately designed by Antoni Gaudi. It is a supremely beautiful feat of structural engineering. Begun in 1882 in stone, the construction continues today predominately in reinforced concrete. The towering structure dominates the skyline of the Catalan capital – Barcelona – and has become a symbol of pride and identity for the Catalan culture.

"Based on the use of innovative shapes of naturalist style"[xi] eight stone bell towers have already been raised to heights exceeding 100m. Four more bell towers are to be constructed using similar techniques, as well as two larger towers and a central dome. The stone construction techniques, on the one hand, give the building the feel of a traditional cathedral, but the unique organic forms, on the other hand, clearly remove the temple from any architectural traditions.

Much of the building's interior is currently being constructed from reinforced concrete. The concrete is pigmented to match the surrounding stone but is distinguishable from the surrounding stone due to the lack of joints. The concrete sits aesthetically well with the stone due to matching colours and similar textures.

Barcelona's Sagrada Familia was to be a stone building capped with mosaics of ceramic tiles. More recent architects to work on the project have incorporated reinforced concrete into the building's construction, but through the use of pigmentation in the concrete, have attempted to make its inclusion as subtle as possible. It is in these concrete areas, however, that Gaudi's geometric forms are best appreciated, as the pure lines of form are not interrupted by the lines of stone joints.

Materiality plays a significant role by revealing the time taken to construct the Sagrada Familia. The evolution in construction from stone to concrete highlights what has been – and still is – a particularly arduous construction process that is estimated to last at least another eighty years.

It is clearly evident that Gaudi's Sagrada Familia is a building with extremely dramatic forms. These forms are predominately crafted out of stone, but it is in areas of the building where concrete is used that the forms are the most visually appealing. The inclusion of concrete in this temple does more than highlight the dramatic forms – it also reveals the time period over which the temple has been under construction.

. . . .

By comparing different buildings with similar elements of form composition, it becomes clear that a material of monotonous tone and texture – and with few joints – is the best material to convey the form of a building.

The Guggenheim museum in Bilbao, by Frank Ghery, and the Portuguese Pavilion for Expo '98 by Alvaro Siza both include rectilinear orthogonal forms juxtaposed with fluid organic elements in their designs. It is through the architect's treatment of these fluid elements that the benefits of concrete are revealed.

The Architects have both clad the orthogonal elements of their buildings in a stone that has a strong presence near where the building is sited – marble in Lisbon, and Limestone in Bilbao – giving the buildings an important link to the city in which they stand.

The architects have however treated the curvaceous areas of their buildings in drastically different ways. Ghery has clad his organically curving forms in titanium, whilst Siza's parabolic roof is concrete pigmented a similar colour to the surrounding marble. It is as a result of the architect's treatment of materiality in these curvaceous areas that the buildings express such different qualities. One is able to appreciate Siza's Portuguese Pavilion as a delightful composition of eloquent forms, whilst with Ghery's Guggenheim museum one is fixated on the simmer and reflections of the titanium panels and rarely appreciates the sensual forms the architect has created.

Antoni Gaudi's Sagrada Familia and Le Corbusier's Notre Dame Du Haut are both buildings of dynamic fluid forms, and despite the drastic difference in the building's scale, both serve the purpose of a place of worship. The Sagrada Familia is predominately constructed from stone with concrete being used only in recent years in the cathedral's construction. The chapel at Ronchamp, however, uses different methods of concrete construction throughout which results in different surface textures and tones.

The forms of the Sagrada Familia are more fully appreciated in the areas where concrete has been used. This is because the lines of form are not interrupted as they are when joints in stone occur. The walls of Notre Dame Du Haut are faced with spray-applied concrete which gives the chapel a uniform surface texture, making no visual intrusions into the building's form. Le Corbusier uses conspicuous concrete expansion joints to emphasise certain volumes and to separate them from the whole.

It is evident in these two buildings that the monotonous texture of concrete is excellent for conveying a building's form due to the lack of joints required. Conversely, due to the said lack of joints in concrete – treated correctly – these joints can serve to enhance the buildings form by separating and emphasising volumes.

Through examining four different buildings with fluid curving elements included in their forms, constructed of various materials, the advantages of concrete as a surface material are revealed. Frank Ghery's Guggenheim museum, and Alvaro Siza's Portuguese pavilion for Expo'98 teach us that the monotonous tone and texture of concrete best convey a curvaceous building's form, whilst Gaudi's Sagrada Familia and Le Corbusier's Notre Dame Du Haut reveal the advantage of the large area that concrete can cover without requiring a joint, and the impact these factors have on one's appreciation of form. Concrete is possibly the best material to convey a building's form.

CONCLUSION

Concrete possesses all of the qualities desirable for a building material. It is a strong and durable material that is infinitely malleable, and hence it has been used by architects to create some of the world's most elegant sculptural buildings.

Treated correctly concrete will weather brilliantly. Le Corbusier's Notre Dame Du Haut in Ronchamp – for example – is still in remarkably good condition due to the architect's attention to detail it appears to be a recently constructed building more than 50 years after its completion. Frank Ghery's Guggenheim Museum in Bilbao on the other hand is only six years old yet signs of deterioration and weathering are clearly evident on the building's façades. The architect here used flimsy experimental materials to create a building that will require constant maintenance to remain in good condition.

The Portuguese Pavilion for Expo '98 in Lisbon is weathering well considering the corrosive marine environment where the building stands. This building is in a similar environment to the Guggenheim Museum, and is also a similar age, but it is weathering much more gracefully and growing into its environment. The durability of concrete – however – is best embodied by the Pantheon in Rome, which does show signs of weathering, but for a building that is more than two thousand years old it is in fine condition.

Concrete will become stained and tarnished if a building is not detailed properly and water is allowed to seep across its surface – but when used by a skilful and meticulous architect concrete weathers as well – or better – as any other building material.

Concrete begins its life as viscous slurry, and as a result it is infinitely malleable. It is this quality of concrete that has been exploited by architects to create wonderfully sculptural buildings that are as much art as architecture.

The futuristic curves of the TWA terminal in New York – by Eero Saarinen – is perhaps the building to best exploit the strength and malleability of concrete to create three dimensional curves in almost every surface in the building. Notre Dame du Haut at Ronchamp uses different concrete construction techniques and surface treatment in different elements of the building to create beautiful artistic composition whilst the elegant two dimensional catenaries curve of the suspended slab in the Portuguese Pavilion for Expo '98 in Lisbon is the focal point of the building.

In the Brazilian Congress building in Brasilia, Niemeyer uses existing construction techniques in new ways to create what is perhaps the best artistic composition in architecture, and in the nearby Cathedral he repeats an elegant concrete element to create a breathtaking space.

It is the strength and malleability of concrete that enables architects to produce sculptural evocative pieces of architecture that inevitably become icons for the cities they are built in and the companies they are built for.

Concrete is used prolifically in the construction industry due to its structural qualities. The compressive qualities of concrete are immense and well known, but reinforced concrete has fantastic tensional tolerances as well. Concrete is versatile – it can be pre-cast or in situ – and it can be used in conjunction with other materials like steel.

Pierre Luigi Nervi's Palazzetto dello Sport in Rome is one of the first pre-cast concrete buildings to depart from the crude industrial aesthetic. Nervi – throughout his career – explored the structural qualities of concrete and different construction techniques with remarkable results.

Le Corbusier's Notre Dame du Haut at Ronchamp adapted technology from the aviation industry to create the sweeping concrete walls in his chapel. Here concrete has been used as a cladding for a steel framed building. The Portuguese Pavilion for expo '98 in Lisbon, By Alvaro Siza, explores the tensile capabilities of concrete by suspending a concrete slab on steel cables, resulting in an elegant and evocative outdoor space.

The structural capabilities of concrete are still being explored by engineers and architects. The potential uses of concrete in the construction industry are endless, limited only by the imagination and insight of designers.

Concrete is a wonderful surface material for both the interior and exterior elements of the building. The large area of surface that concrete can cover without joints, and the monotonous nature of the texture and colour of concrete allow one to appreciate the building's form more precisely.

Gaudi's Sagrada Familia in Barcelona demonstrates the advantages of the lack of joints in concrete. In the recent concrete additions to the temple Gaudi's structural elements are more pure and more beautiful as the lines of form are not interrupted as they are in the older areas of the building constructed from stone. The magnificent white walls of Notre Dame du Haut at Ronchamp are white painted spray applied concrete. Here joints have been used sparingly so where a joint occurs a visual separation is achieved – separating the different forms of the building. The imposing eaves of the church expose the fossilised imprint of the form boards used during construction – giving the concrete a rough brutal texture.

Concrete as a surface material need only be interrupted by expansion joints, or breaks in a continuous pour. The surface texture and colour is consistent, hence this is a material suited to creating sculptural buildings.

Some of the world's most elegant buildings have been constructed from concrete. Concrete has aesthetic and structural qualities – it is malleable, versatile and weathers well. Concrete is a material that is perceived as being cold, grey, and dull – but skilled architects have utilised the intrinsic qualities of the material to create some of the world's most magnificent buildings.

END NOTES.

[i] Guggenheim Museum pamphlet.
[ii] Van Hensbergen, G. *Gaudi – the Biography*. Harper Collins, London 2001.
[iii] Guggenheim Museum pamphlet.
[iv] Gossel, P. and Leuthauser, G. *Architecture in the 21st Century*. Taschen, Germany 1991.
[v] Niemeyer, O. Pritzker Prize Acceptance Speech. Cited www.pritzkerprize.com.
[vi] Gossel, P. and Leuthauser, G. *Architecture in the 21st Century*. Taschen, Germany 1991.
[vii] Thiel-Siling, S. *Icons of Architecture*. Prestel, New York 1998.
[viii] Gossel, P. and Leuthauser, G. *Architecture in the 21st Century*. Taschen, Germany 1991.
[ix] Guggenheim Museum pamphlet.
[x] Guggenheim Museum pamphlet.
[xi] Sagrada Familia pamphlet.