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Candidate session number			
Candidate name			
School number			
School name			
Examination session (May or November)	MAY	Year	2013

Diploma Programme subject in which this extended essay is registered: VISUAL ARTS  
(For an extended essay in the area of languages, state the language and whether it is group 1 or group 2.)

Title of the extended essay: HOW WOULD ONE DETERMINE THE ESSENTIAL BALANCE BETWEEN FORM AND FUNCTION IN THE CASES OF FOUR 21<sup>ST</sup> CENTURY PEDESTRIAN BRIDGES?

**Candidate's declaration**

*This declaration must be signed by the candidate; otherwise a grade may not be issued.*

The extended essay I am submitting is my own work (apart from guidance allowed by the International Baccalaureate).

I have acknowledged each use of the words, graphics or ideas of another person, whether written, oral or visual.

I am aware that the word limit for all extended essays is 4000 words and that examiners are not required to read beyond this limit.

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Name of supervisor (CAPITAL letters)

*Please comment, as appropriate, on the candidate's performance, the context in which the candidate undertook the research for the extended essay, any difficulties encountered and how these were overcome (see page 13 of the extended essay guide). The concluding interview (viva voce) may provide useful information. These comments can help the examiner award a level for criterion K (holistic judgment). Do not comment on any adverse personal circumstances that may have affected the candidate. If the amount of time spent with the candidate was zero, you must explain this, in particular how it was then possible to authenticate the essay as the candidate's own work. You may attach an additional sheet if there is insufficient space here.*

has been an excellent student for the way she has taken responsibility for the selection of the topic, the research and analysis; and for the drafting and presentation of her essay. She has been an excellent time manager also. She needed a little help with the selection of bridges which she could actually visit and appraise. The research question was entirely her own choice but she needed some help with structuring the essay and developing the depth in her analysis. As an intending architect this was a very good experience for her. She has learnt a lot and is a little better prepared for university.

*This declaration must be signed by the supervisor; otherwise a grade may not be issued.*

I have read the final version of the extended essay that will be submitted to the examiner.

To the best of my knowledge, the extended essay is the authentic work of the candidate.

I spent  hours with the candidate discussing the progress of the extended essay.

Supervisor's signature:

Date:

**Assessment form (for examiner use only)**

**Achievement level**

<b>Criteria</b>	Examiner 1	maximum	Examiner 2	maximum	Examiner 3
A research question	2	2		2	
B introduction	2	2		2	
C investigation	3	4		4	
D knowledge and understanding	3	4		4	
E reasoned argument	4	4		4	
F analysis and evaluation	4	4		4	
G use of subject language	4	4		4	
H conclusion	2	2		2	
I formal presentation	4	4		4	
J abstract	2	2		2	
K holistic judgment	3	4		4	
Total out of 36	33				

# **How would one determine the essential balance between form and function in the cases of four 21<sup>st</sup> century pedestrian bridges?**

Words: 3975

## Abstract

My research examined the extent to which the essential balance between form and function varies, through an analysis of four 21<sup>st</sup> century pedestrian bridges. I started my research by reading books about bridges for more understanding of problems concerning their design and then chose to focus my research on contemporary footbridges. However once I had chosen my specific topic and bridge examples, I did my further investigation on the internet due to the abundance of information not readily available in books. I chose bridges which I thought had some similarities in their design requirements, yet were significantly different in their engineering and aesthetics. I analyzed each bridge individually, drawing individual conclusions and I went to visit the two London bridges first-hand as part of my investigation. I then compared and contrasted them to help me arrive at an answer to my research question. Through my investigation of the four bridges, I concluded that the Rolling Bridge and the Ponte della Costituzione had a balance in favor of their appearance which ultimately led to functional flaws within their designs. The case of the London Millennium Bridge was less clear, as although initially having a highly publicized design fault, the end result was with an essential balance effectively restored. The Gateshead Millennium Bridge I concluded had most successfully achieved this essential balance between form and function, as it is an original engineering solution which is beautiful in its own right.

Words: 238

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“Few man-made structures combine the technical with the aesthetic in such an evocative way as bridges.”

*David J. Brown, Bridges: Three Thousand Years of Defying Nature*

Finding the essential balance between form and function is arguably the greatest challenge for architects and designers, and determining exactly where that balance can often cause heated debates. In this essay I will examine the degree of balance between form and function in four modern footbridges, to determine how close they come to an ideal where the balance between functional structure and appearance is resolved fully to give the very best of both.

I chose to focus on footbridges because with such bridges form can be given more precedence than with road or rail bridges as they don't need to bear the same loads and generally have a shorter span, so engineering considerations are less paramount. Many cities and towns around the world chose to mark the turn of this century by building landmark bridges, as bridges can be a symbol of human connectivity, technological prowess and artistic achievement at the same time as performing a useful function. The trend for commissioning new bridges as a means of putting a location on the map, by having a significant piece of structural art, has continued well into the new century. All four of the bridges I investigated have been built since the year 2000; two were specifically built to mark the millennium and therefore consideration of aesthetics was particularly important. (3)(4)

The four pedestrian bridges I chose to investigate have differing balances between their form and function. Two are fixed bridges and two move to allow for the passage of boats. I included the Gateshead Millennium Bridge as it is both a unique piece of engineering and an acknowledged aesthetic success. Although it is a far smaller bridge than the others, the Rolling Bridge in London was included because it is fascinating both for its innovation and its form. I chose the other two bridges - the London Millennium Footbridge and the Ponte Della Costituzione in Venice - because they have both had well-publicised design failings. Through this investigation I will explore the degree of balance between functionality and aesthetics achieved in each of these bridges.

Before analysing each of the bridges in this study, it is important to consider the various factors that can influence the form of a bridge.

The form of a bridge is always dictated to some extent by its function, which may be to carry pedestrians, motor vehicles, trains, and sometimes water in the form of aqueducts. A good design must satisfy all the functional requirements, which will depend on what the bridge is intended for, where it will be, what sorts of loads it must carry, the potential natural phenomena, such as earthquakes and hurricanes, it will be subjected to, and so on (4).

Other factors that contribute to the form of a bridge include the technology and materials used and these have evolved throughout history. For example, the Roman invention of arch supported bridges marked a significant change in form, as did the invention of the modern suspension bridge in the 19<sup>th</sup> century, along with the use of iron and steel. The properties of differing materials have a huge impact upon a bridge's form as they vary significantly in terms of their strength, workability and durability. Materials also differ in their texture and colour which affects the final look of the bridge. (3)

Cost has an un-escapable significance on the form of bridges, as some materials and methods of building are much more expensive than others. However, this analysis focuses on the relationship between form and function and not on budget considerations.

Consideration of aesthetics has long been important in the design of major bridges that are highly visible in an important part of a city and the most famous bridge designers, including Thomas Telford, John Roebling and Robert Maillart, always made aesthetics a deliberate element in their work. The world's most striking bridges such as London's Tower Bridge, New York's Brooklyn Bridge, Sydney's Harbour Bridge and San Francisco's Golden Gate Bridge have become icons, representing their country's economic power, engineering capabilities and architectural prowess (3). However, aesthetics often seem to have been ignored when it came to building less important bridges, resulting in many functional eyesores. That appears to be changing. The following quote from *Bridge Aesthetics – Structural Art* reflects comments in a number of recent bridge publications: "The public often expresses concern over the appearance of bridges, having recognized that a bridge's visual impact on its community is lasting and must receive serious consideration... Thus, engineers all over the world are being forced to address the issues of aesthetics."



Figure 1:  
Tower Bridge, London

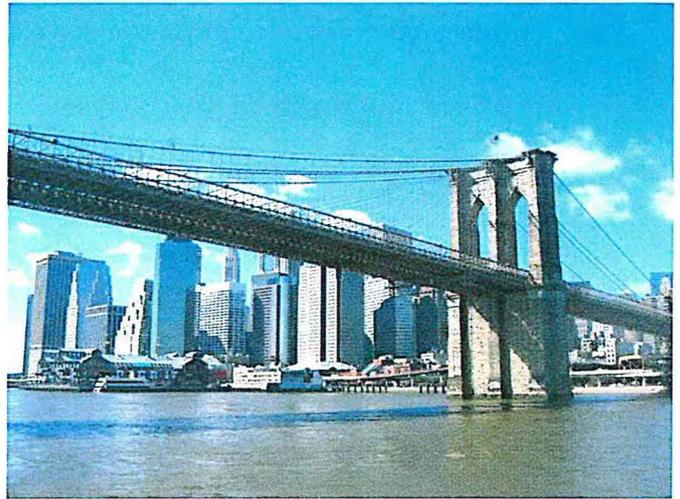


Figure 2:  
Brooklyn Bridge, New York



Figure 3:  
Harbour Bridge, Sydney

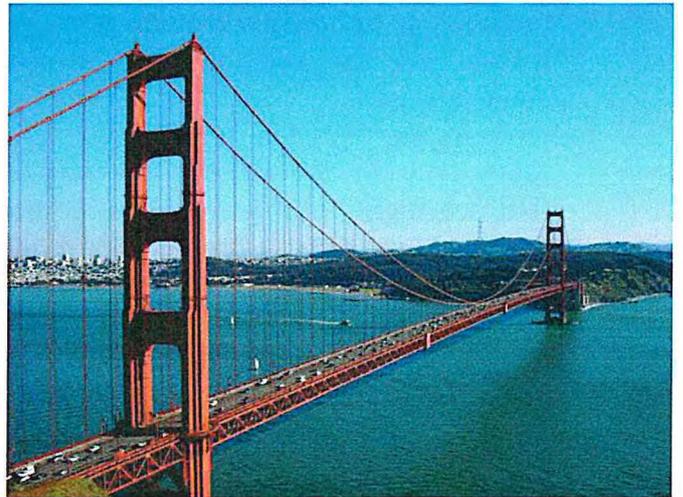


Figure 4:  
Golden Gate Bridge, San Francisco

## Gateshead Millennium Bridge, UK

In 1996 an architectural competition was launched by the Gateshead Council to design a landmark bridge for the new millennium that would allow a crossing over the River Tyne to link the new developments on each side. The design brief stated the function of the bridge was to allow crossing by pedestrians and cyclists, whilst being able to allow boats to pass underneath. Furthermore an aesthetic requirement for the bridge was not to overshadow or obstruct the view of the existing bridges along the river (8).

There are many ways, some relatively simple, to create moveable bridges so as to allow passage for boats, such as Swing bridges (which pivot turning the bridge sideways over the water), Bascule bridges (where the bridge divides in the middle with both sides lifting) and Vertical-lift and Table bridges where a section moves vertically upwards (5). However, the winning design by architects Wilkinson Eyre and structural engineers Gifford was a unique solution to the specification – a tilting bridge.



Figure 5

The Gateshead Millennium Bridge is sometimes referred to as the ‘winking’ or ‘blinking eye’ bridge, as it consists essentially of a pair of steel parabolic arches, one forming the deck of the footbridge itself, the second counterbalancing it. These two arches pivot through  $40^\circ$  around fixed points on each side of the river as a single, rigid structure. As the pedestrian deck rises to allow boats to pass, the supporting deck lowers. It takes only 4.5 minutes to rotate from closed to open (6). By using this tilting mechanism based on counterbalance, a minimum of energy is required to operate the bridge.

In terms of functionality, the Gateshead Millennium Bridge scores highly by any standards. A truly innovative piece of engineering, it has operated safely and reliably since its inauguration in 2001. It opens and closes quickly, with minimum delays for

pedestrians or boats, and is energy-efficient. It even cleans up its own litter – anything dropped on the deck rolls into special traps at either end each time it opens (7). At the same time, it is an acknowledged aesthetic success. Awarding it the Outstanding Structure Award in 2005, the International Association for Bridge and Structural Engineering (5) said the following: “The soaring arch provides an instant visual reference to the Tyne Bridge beyond, but also presents a slender profile against the skyline, interpreting and updating the structural and aesthetic order of its historic neighbour. Visually elegant both when static and in motion, the bridge offers a great spectacle during its opening operation – during the day and by night” (21). In 2003 the bridge received from the UK Institution of Structural Engineers, an award which recognises “an outstanding structure which demonstrates excellent coordination of all aspects of the engineering elements and services combined with elegance, life-time economy and respect for the environment” (22). Since balance between form and function is a key criteria for both of these awards, the Gateshead Millennium Bridge is clearly a fine example of a structure that has achieved that essential balance.

The success of this bridge was summed up by the leader of Gateshead Council, Mick Henry, who said: “When we chose the design for the Gateshead Millennium Bridge, we knew we had something very special. The many awards and accolades it has received for its design and construction has certainly proved us right. Local people have taken the bridge to their hearts as a symbol of Gateshead’s renaissance” (20). Evidence that the bridge has achieved iconic status in a relatively short time period is that it has been featured on a first class stamp and on a new pound coin minted in 2007 (7).

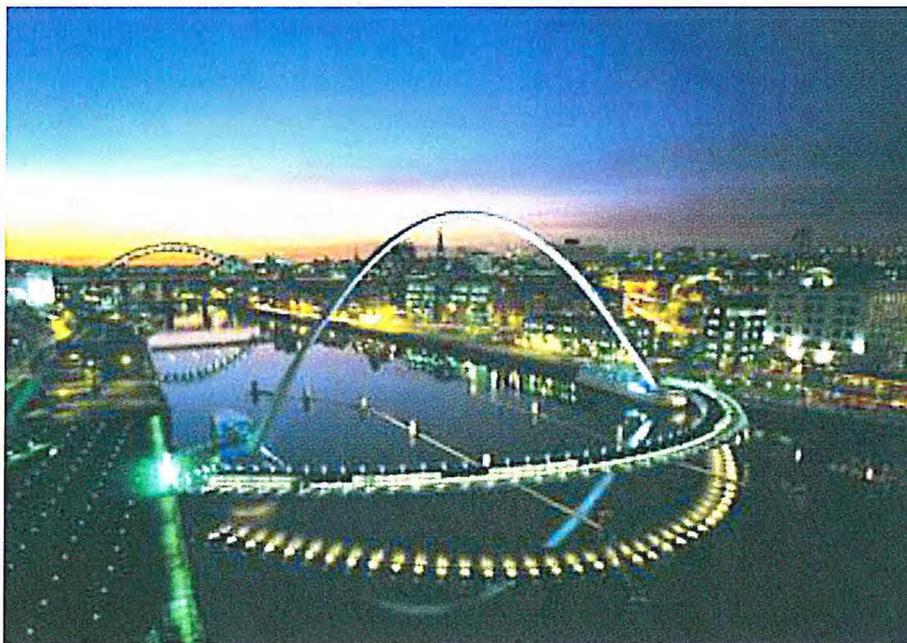


Figure 6

## The Rolling Bridge, London, UK

The Rolling Bridge sits across an inlet of the Grand Union Canal within Paddington Basin in London. It was designed by Thomas Heatherwick, a designer known for his innovative use of engineering and materials (10). Commissioned by the Paddington Development Corporation in 2004, the design brief called for a bridge to provide pedestrian access for workers and residents in the area whilst allowing for a boat that moors in the inlet to move in and out.

There were numerous possible solutions to the design brief, the simplest for such a short span (only forty feet across the inlet) being a drawbridge (9). However Heatherwick believed that most drawbridges look “broken”, and was looking for “something more transformative” (11). His solution was a wholly original curling bridge consisting of eight triangular segments. When down, it lies straight across the inlet; to allow the boat access to its mooring, the bridge curls up, forming an octagonal sculpture on one side. It is engineered using a series of hydraulic rams within the railing either side of the bridge, and pistons within the parapets which power its movements.

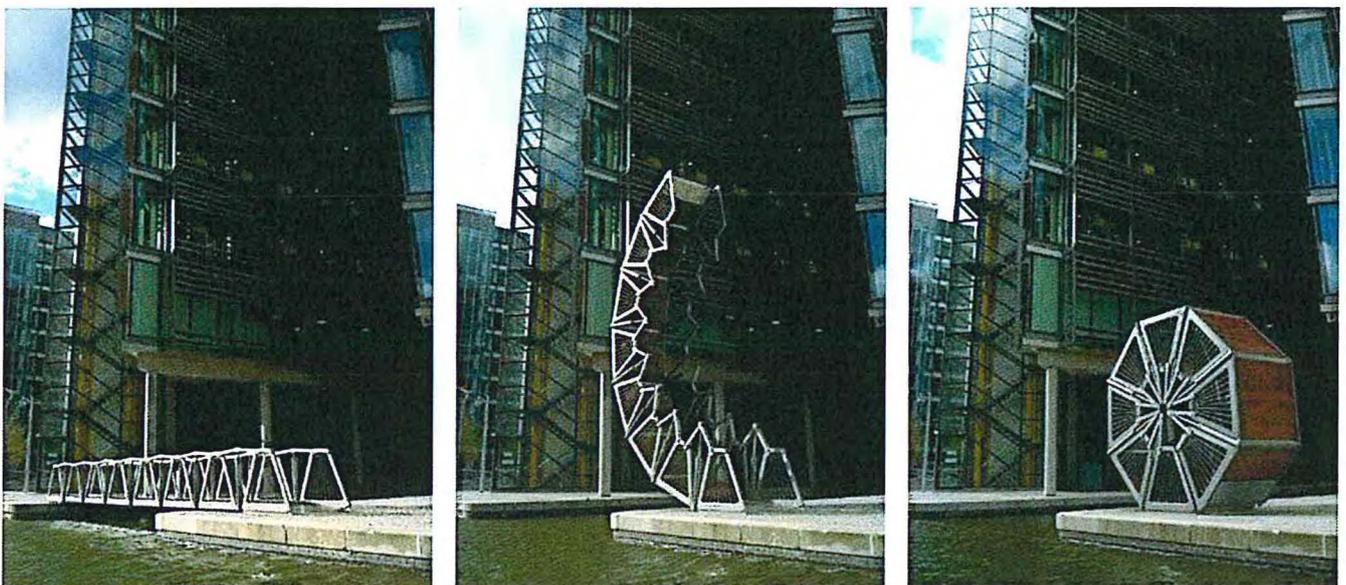


Figure 7

I included the Rolling Bridge as part of this analysis because it seemed an ingenious and aesthetically beautiful solution to meet the design brief. However, as I discovered when I went to see it in June 2012, the bridge has a major functional issue – unreliability: it was broken, and had been for several months. Merchant Square Estates, which maintains and opens it, said that the pistons were ‘temperamental’. It was closed for much of 2008 when it had maintenance issues, was subsequently repaired and functioned from April 2009 until early 2012 when it stopped working again (10). While the fault apparently lies in the construction, not the design, the choice of such a complex and sculptural piece of engineering for such a small span undoubtedly increased the risk of unreliability.

A second functional drawback is the length of time the bridge takes to curl and uncurl – around two minutes for each operation, which is a long time relative to the length of the span. A YouTube video attracted a number of negative comments about its slow pace, such as “bridge needs to go a little faster, people got sh\*\* to do and cross”. Fortunately it takes less than a minute to walk around the inlet by another route, so while the bridge is opening there is another alternative for those in a hurry; likewise it has not been a huge inconvenience when it has been broken. The ease of an alternative crossing may well have been a factor in the balance between function and form in this bridge leaning heavily towards form.

Heatherwick himself said of the Rolling Bridge: “how it works is the extraordinary aspect of it” (11). When flat it appears as an unremarkable steel and timber footbridge. It is the naturalistic way it moves and the elegant geometric form it takes that make it so aesthetically appealing (12). In the year it opened, 2005, the bridge won the British Structural Steel Design Award (9). The awarding organisation called it a “delicate balance of art, machine and structure” and the judges commented: “When rolled the machine has all the appearance of a Leonardo sketch” (23).

Given its functional drawbacks, which to some extent arise from its complex design, the Rolling Bridge cannot be said to have achieved an essential balance, but rather to favour appearance and innovative engineering over function. It is in fact as much a moving sculpture as a means of crossing the inlet. This is underlined by the fact that it is opened not just for boat passage but every Friday at noon just for the many spectators who come to see it in operation. While not a wholly successful bridge, it is nonetheless a fascinating work of art and engineering.

## London Millennium Bridge, UK

The London Millennium Footbridge was designed by architects Foster and Partners, engineering company Arup and sculptor Sir Anthony Caro for a competition in 1996 organized by the Southwark Council and the Royal Institute of British Architects. Construction began in 1998, and it open on the 10<sup>th</sup> of June 2000 (13).

Its function was to be a pedestrian bridge which would cross the River Thames linking two very busy parts of London – Bankside, by the Tate Modern gallery, with the City, below St. Paul’s Cathedral. The brief specified that the bridge should not obstruct the view along the Thames, should not be out of scale with neighbouring historic bridges and had to meet legal height restrictions protecting views of St. Paul’s Cathedral (3).

The winning architectural vision for the bridge was for a ‘thin ribbon of steel’ by day, illuminated to form a ‘blade of light’ by night (3). To achieve this and meet the required restrictions on height and scale, the structural design was an unusual form of suspension bridge in which the tensioning cables are below deck level, creating a very shallow profile and also ensuring unobstructed views from the deck.

On the aesthetic side of the form/function equation, the London Millennium Bridge is generally regarded as scoring highly, especially for the way fits in with its surroundings. It does not try to compete with the grandeur of St. Paul’s, but its simple, clean lines give it an elegance of its own (4).

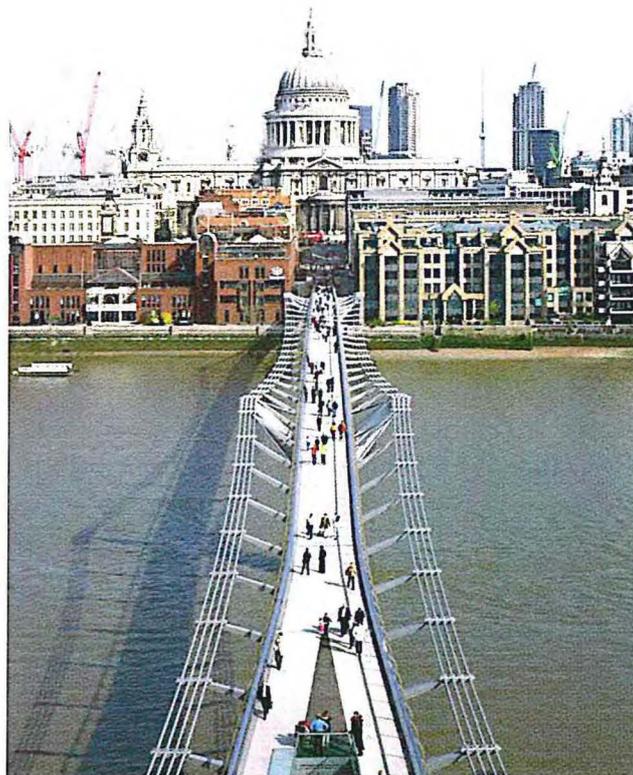


Figure 8

However, the bridge had a highly publicised design flaw which ultimately forced it to be closed for almost 2 years, while modifications were made. The fault was discovered on the day it opened: with up to 2,000 people walking across it at any one time it began to sway noticeably making people clutch the railing nervously and feel 'seasick'. It was instantly dubbed the 'wobbly bridge' by the media, a nickname still affectionately used by Londoners. After limiting numbers on the bridge for a day, it was closed (3).

The designers had taken into account the well-understood issue of vertical vibration: soldiers have long been ordered to break step when marching across bridges because of the vibration synchronised marching can cause. However, the wobble on the Millennium Bridge was a sideways one that had not previously been recognised – now known as “synchronous lateral excitation”. It was caused by a natural human reaction to lateral movements – if we walk on a surface that is swaying, we compensate and stabilize ourselves by spreading our legs further apart and begin to sway in synch with the bridge and others walking on it. This exacerbates the sway by increasing the lateral push. When there are enough people on a bridge doing this, the lateral push can overcome the bridge's ability to absorb it – causing the bridge to move. This problem had been documented in 1993 by a Japanese team from the University of Tokyo who conducted experiments on a heavily used cable-stayed pedestrian bridge. However, their research was published in a journal of seismic engineering and bridge engineers were unaware of it (3).

The solution engineers came up with was installing shock absorbers called viscous dampers on the underside of the bridge to control the horizontal movement, along with weights on springs to reduce the vertical motion. The bridge was re-opened on February 22<sup>nd</sup> 2002 and has not wobbled since (3).

Though there was a strong focus on appearance in the bridge's design, it would be unfair to attribute its flaw to a lack of focus on structural function, as the fault that emerged was due to a virtually unknown phenomenon. Although the bridge was closed for an extended time, the problem was fixed in a way that has not detracted from its aesthetics. Because the bridge is fundamentally a good design which ultimately achieved the essential balance between form and function, it has been able to overcome the initial bad PR and has already achieved iconic status. Evidence of this was seen when it featured in the film *Harry Potter and the Half-Blood Prince* being destroyed by evil 'death-eaters', perhaps because it is closer to the hearts of the Harry Potter generation than older iconic bridges such as Tower Bridge (13).



Figure 9

## Ponte Della Costituzione (Constitution Bridge), Venice, Italy

The Ponte Della Costituzione was designed by Santiago Calatrava, who was chosen by a public selection process when the City of Venice decided to commission a new bridge in 1999. Calatrava is a Spanish architect, structural engineer and sculptor who has a worldwide reputation for designing striking bridges (14). The bridge provides a pedestrian connection across the Grand Canal between the Santa Lucia railway station on the north side and the Piazzale Roma on the south side, where Venice's main bus station is located (14). It opened in 2008 amid much controversy – an official opening was cancelled due to fear of protests - and has been subject to a good deal of criticism from the public for a variety of reasons (15).

The controversy over the bridge began long before it was even built - the necessity for another bridge at this location was questioned, as the Ponte degli Scalzi is just a short distance away. Many Venetians felt there were other sections of the Grand Canal where a new bridge would be of more use. The choice of location seems to have been driven more by a desire to build a new landmark structure in a high-visibility place. Calatrava himself said: "The bridge is important both functionally and symbolically, connecting arriving visitors to the city and welcoming them to Venice with a panoramic view of the Grand Canal" (16). In addition, there is a long history of resistance to modern architecture in Venice, a historic city known for its beautiful, old buildings and bridges.

Calatrava's design was a shallow arch truss bridge, slightly wider in the centre than at the banks, with a deck of stairs. The framework is entirely of steel, and comprises several arches connected with steel beams. The stairway is paved with alternate steps of tempered glass and Istrian stone, illuminated from below. The parapets are also tempered glass with a bronze handrail that is lit up at night (17).



Figure 10

Problems with functional aspects of the bridge's design arose shortly after it opened. First, it came in for a lot of criticism for the lack of disabled access due to the steps. With its many ancient bridges Venice is an extremely challenging place for those with disabilities and the failure to ensure that this new 21<sup>st</sup> century bridge could be used comfortably by those with disabilities caused an outcry (17). Subsequently a cable-car pod was added to transport disabled people across, but as an afterthought to the original design it has detracted from its aesthetics (16).

In addition, several people crossing the bridge have tripped and hurt themselves, resulting in the City of Venice facing legal claims. According to a report in *The Daily Telegraph* on 22 July 2012: "Pedestrians who lost their footing have blamed the bridge's irregularly spaced steps, some of which act as viewing points, and the disorienting optical effect of the sectioned stone and glass flooring." What is more, there is anecdotal evidence that in wet weather the glass steps make people nervous of slipping and as a result people file down the central non-glass section when it is raining (19).



Figure 11

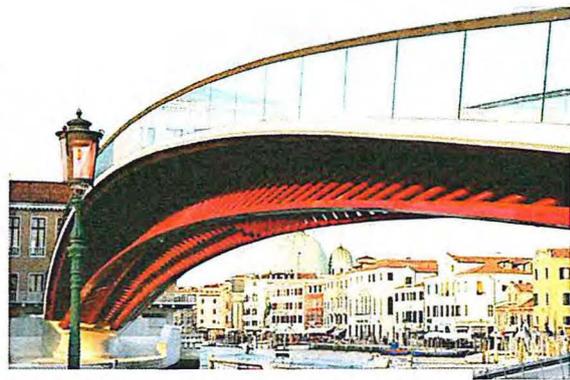


Figure 12

Another major drawback is the failure to have a ramp for wheeled luggage. What is more, wheeled suitcases or handcarts weighing over 20 kilograms have been banned from the bridge to protect its glass and stone surface (16). This is a considerable inconvenience to locals and visitors alike, many of whom have luggage due to the location of the bridge between two major transport hubs (20).

It seems that the faults of this bridge are due to too little attention being paid to the "user-friendliness" of its function versus its aesthetics. However, opinion on the aesthetic quality of Calatrava's bridge, which he calls his "most beautiful", have been mixed. Some commentators regard it highly. For example, Kathryn Heath from the Department of Architecture at the University of Bath praises the use of elements that help it blend into its surroundings, such as Istrian stone that is a traditional local material and the 'Venetian Red' color of the structure which is reflected in the surrounding red brick buildings. She concludes: "It is an example of a combination of great architecture and engineering put into context, achieving a stunning end result." On the other hand, there are many who dislike its appearance. For example, *Venice: An Architectural Guide* by R.J. Goy refers to "... some recent eyesores, including Santiago Calatrava's hideous and impractical Ponte della Costituzione...". Some of the

bridge's detractors have likened it to a "lobster" because of its red colour and segmented appearance from underneath (15). It may be that the bad feeling towards the bridge due to its design faults has had a knock-on effect on how people view the bridge as a whole. The perception of its aesthetic value may have been diminished by its functional failings. Certainly it does not seem to have achieved the essential balance between the two.

Many municipalities around the world have chosen to erect bridges as a way of marking the new millennium, however not all have been successful in fully resolving the balance between function and aesthetics to give the very best of both. My analysis of four selected bridges has shown that they have varying balances between their function and appearance.

In the cases of the Rolling Bridge and the the Ponte della Costituzione, the balance is tilted in favour of appearance. Although the Rolling Bridge is a creative gem of engineering, it is unreliable and inefficient for use as a pedestrian foot bridge. The overriding focus on its mechanics and aesthetics make it more a moving sculpture than a functional bridge. Likewise the lack of attention to the needs of users at the design stage resulted in the Ponte della Costituzione being functionally awkward, though is it certainly a structure with character and a striking new Venice landmark.

The balance in the London Millennium Bridge is less clear. While it had a highly publicized design fault, it was not due to a lack of focus on its functional structure, nor because precedence was given to aesthetics, but due to a phenomenon that could not have been anticipated. Once the problem was fixed, without materially affecting the look of the bridge, the essential balance was effectively restored.

Of the four, the Gateshead Millennium Bridge most successfully achieved an essential balance between function and aesthetics from the start. It seems to reinforce the concept that the greatest and most original engineering solutions can be beautiful in their own right.

Ultimately, whether a bridge has achieved the essential balance between form and function can best be determined by the public response to it. Where that balance has been achieved, the people who use the bridge on a daily basis have a positive emotional connection to it, just as they would with any good work of art. But in the case of a bridge, that emotional connection can only be established if aesthetics and functionality are in balance. It is hard to love a bridge that is unsafe, unreliable or awkward or inconvenient to cross; equally it is hard to love a bridge that is functionally efficient but has no aesthetic qualities. Where there is an essential balance a bridge will often achieve iconic status, as shown with the Gateshead and London Millennium bridges.

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Figure 10: July 24, 2012

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Figure 11: July 10, 2012

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Figure 12: July 10, 2012

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