ADJUSTING TO THE NEW REALITIES OF BRIDGE AESTHETICS, ENGINEERING AND ARCHITECTURE

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ABSTRACT

The background issue which is addressed in this paper relates to the current realities with regard to bridge aesthetics, engineering and architecture, and the changing balance of these three elements of bridge design and construction projects in Canada.

The objective of the paper is to set out with reference to the Canadian experience, a review of past practice and current trends, leading to an assessment of the future direction of the importance of bridge aesthetics. This is considered in balance with practical bridge engineering design and construction, innovative bridge architecture, and reasonable construction costs.

The methodology involves looking back at the history of bridge engineering in Canada with a particular emphasis on bridge aesthetics, and recent trends which have affected Canadian bridge engineering and architecture, including inventive bridge engineering and architectural work in Europe. A number of outstanding Canadian bridges are examined with consideration of their aesthetic appeal and value including the Angus L. Macdonald Bridge in Nova Scotia, the Jacques Cartier Bridge in Montreal, the Thousand Islands Bridge in Ontario, the Esplanade Riel Bridge in Winnipeg, the Broadway Bridge in Saskatoon, the High Level Bridge in Edmonton, and the Kicking Horse Canyon Bridge in British Columbia, amongst others, touching on several of the Provinces and Territories.

Issues discussed include:

- Is there necessarily a compromise between aesthetics and function?
- Are there additional costs associated with outstanding aesthetics?
- Where are signature bridges most appropriate?
- What is the value to society of a bridge with pleasing aesthetics?
- Should bridges blend with the environment?
- What can we learn from recent European experience?
- What is the relationship between the Design-Build method, and bridge aesthetics?
- What is the effect of design competitions?
- How have computers affected modern bridges?

The conclusions of the paper relate to all of these topics. The paper sets out some thoughts as to the overall relative importance of bridge aesthetics, engineering and architecture. Consideration is given to how these elements have worked together in the Canadian experience to date, and to how they may be affected by trends in the future.

INTRODUCTION

Seeking a balance amongst practicality, long life, safety, serviceability, constructability and cost efficiency, has been the fundamental challenge of bridge design since the beginning of time. In Canada as progressively more bridges are required, new trends including the use of innovative construction materials and the detailed consideration of the environmental effects of bridge designs, have become more important. This process has been paralleled by extensive public involvement in the design process, consideration of environmental sustainability, and an increased focus on the way bridges connect with the people who use them. This is demonstrated by the new trends in universal accessibility for footbridges, cycling lanes, landscaping, and the aesthetic impact of bridges and the emotional reactions that they create. This paper will discuss some ideas related to these new realities and will provide some insight from both the engineering and architectural perspectives.

HISTORY IN CANADA

Canada has an extensive history in practical bridge design and construction, as befits a frontier nation. Making use of timber and stone and later iron, steel and concrete, early bridge designers and builders first focussed on practicality and efficiency. The original Union Bridge crossing the Ottawa River at the Chaudière shows that such bridges could be of pleasing aspect as well as being practical, this bridge being the first connection between Upper Canada and Lower Canada in Ottawa. It was an iron suspension bridge constructed in 1843 by Samuel Keefer. This bridge was replaced by a truss bridge of no particular aesthetic merit and it in turn was replaced by the current truss bridge below the Chaudière Falls. The original arch on the Quebec side of the bridge in which the suspension bridge anchorages were located, remains in service and, like many stone arches, it is intrinsically pleasing to the eye, in sharp contrast to the current truss. A 1970s proposal to replace the truss with a suspension bridge met with scepticism; but perhaps its day will come again.

Figure 1: Union Suspension Bridge, Ontario-Quebec

The many timber trestle bridges built by the Canadian Pacific Railway across Canada, and by other railways in the 19th Century, have generally not endured, but some of them had a certain grandeur by virtue of their scale and setting and, even though many of them are gone, they have become a part of the collective Canadian consciousness in the context of the railways. Although constructed for utilitarian purposes, many of these high truss structures have a certain grandeur. A typical structure is shown.

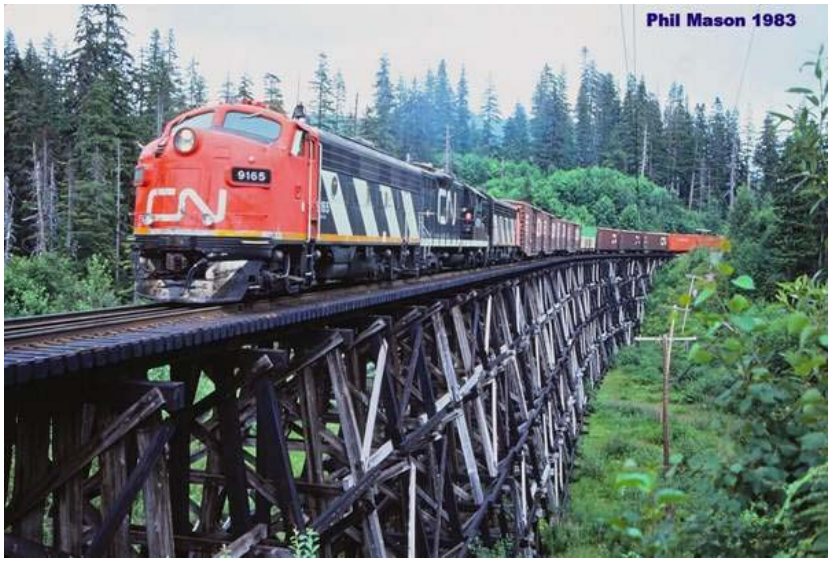

Figure 2: Timber Trestle

The iron and steel structures which followed as the archetypal railway structures in Canada, such as the Lethbridge Viaduct, still appeal today as structures with some intrinsic merit partly derived from their scale.

Figure 3: Lethbridge Viaduct, Alberta

Figure 4: Quebec Bridge, Quebec

The most majestic of these bridges, however, is the Quebec Bridge which includes an 1800 foot cantilever span which is still, and almost certainly always will be, the world record cantilever span, slightly exceeding the span of the Forth Rail Bridge in Scotland. It is an impressive bridge by any standards but it seems unlikely that aesthetics were the key concern in its design. Its dimensions can likely be more attributed to the reaction of the bridge designers to a previous attempt to erect a bridge at this site which had resulted in collapse of the structure during construction. If Canada has built a bridge that will last forever, this may well be the bridge.

An example of a bridge built at the same time as the Quebec Bridge is the Old Mill Bridge over the Humber River in Toronto. This bridge was designed by Frank Barber and it is evident that aesthetics were a key factor in its design as it is a filled concrete arch structure with a stone facing. It is quite a successful example of a bridge which is not what it appears to be, and it fits well with the nearby Old Mill and the pastoral setting in the Humber Valley.

Bridges like this are sometimes criticized but one must take care in such cases. The Tower Bridge in London, for example, was the subject of considerable criticism when it was built as its towers are steel disguised as stonework. It looks like it could be several hundred years old apart from the fact that it is an operating bascule bridge originally powered by steam engines. These engines are still in place although the bridge is now electrically operated. Built in 1895, it demonstrates how perception can change as it is now virtually impossible to envisage London without Tower Bridge.

Similarly the Old Mill Bridge still is a pleasing addition to the environment of the Humber River.

Figure 5: Old Mill Bridge

An example of a true stone bridge is found in Pakenham, Ontario, and it appears that the designer of this bridge had a sound sense of aesthetics, or perhaps the good appearance of the bridge evolved naturally from the use of available materials and functional requirements.

There are many other examples of early bridges across Canada which demonstrates a variable balance amongst practicality and functionality and aesthetics.

It seems likely that in many of these early bridges the key drivers were the availability of suitable materials nearby and the skills of the designers and builders.

An elegant example is the Broadway Bridge in Saskatoon.

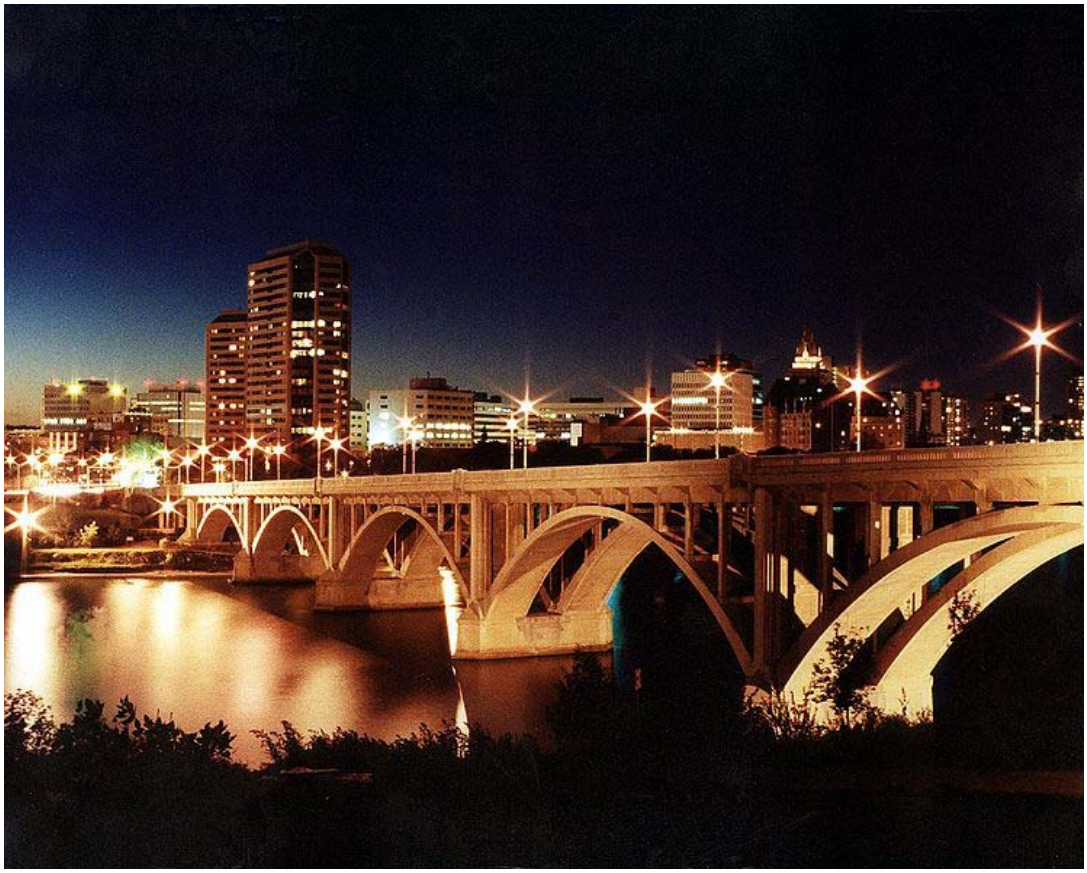

Figure 6: The Broadway Bridge, Saskatoon

The skills of a bridge designer that has the ability and creativity to design visually pleasing structures while maintaining structural efficiency is well exemplified through the design of the Broadway Bridge over the South Saskatchewan River in Saskatoon. The structure boasts the natural strength, elegance and simplicity arch bridges can provide. The bridge was designed by Chalmers Jack Mackenzie. This multi-span concrete open spandrel bridge boasts an elegant engineering design that is satisfying, simple and economical.

RECENT TRENDS IN CANADA

Within the past few decades Canadian bridge designers and the responsible government organizations, have increased focus on the aesthetic aspects of bridges, both new and old. Designers now tend to spend significant effort considering the visual aspects of bridges in their settings and to pay particular attention to maintaining the heritage value of existing structures while also implementing the design and construction practices of the current time period. In 2005, Alberta wanted to ensure that aesthetically pleasing and functional bridges were constructed in the Province and to that end they created documentation to aid designers. Other municipalities and governing bodies have also developed aesthetic guidelines and heritage evaluation techniques, such as the Ministry of Transportation Ontario's *Aesthetic Guideline for Bridges,* and the Ontario *Heritage Bridge Guideline*.

Another recent trend in Canada is attempts (so far not very successful) to reduce the carbon footprint of infrastructure projects throughout the construction process and life cycle of a typical

bridge. The measured carbon footprint is typically considered as a part of the broader environmental assessment process. Efforts to quantify this are not very convincing so far in the context of bridges.

While in recent years, Canada, in common with many other countries, has seen an increased interest in the aesthetics of bridges, this is an element of bridge design which is not new. There have been many elegant bridges built world-wide in the past, and even in the very distant past, which included outstanding aesthetics. Some of these bridges as noted date back hundreds, and even thousands, of years and are still appreciated today. In the West, however, with the coming of the industrial age, a certain spare utilitarianism is evident in many bridge designs. There is a mathematical beauty in some of these bridges such as the bridges of Robert Maillart in Switzerland including the Salginatobel Bridge. But, in other cases, this utilitarianism seems to be simply an industrial expression devoid of mathematical elegance, for example in the case of the typical highway overpass which is generally utilitarian. All of these bridges are engineering expressions and have served their purpose well. One of them, however, is a world-renowned landmark and the others are more or less anonymous and unknown. And so, the question arises as to what difference exists between these engineered structures in terms of aesthetic appeal.

The answer may be that the emotional response to each of these bridges is quite different. In the case of the Salginatobel Bridge, the emotional response is typically one of wonder and awe that such a bridge could have been constructed. In fact, the falsework which supported the bridge during construction was just as aw-inspiring as the bridge itself.

Figure 7: Salginatobel Bridge, Switzerland

By contrast, the bridge shown below (an extreme example of utilitarianism) elicits the reaction of curiosity and perhaps trepidation, as to why the bridge is configured as it is. It may be said that it does not lift the spirits.

Figure 8: Uninspiring Bridge

Perhaps it is worthwhile that we consider in Canada how our bridges as we construct them in coming years can, if only in a small way in many cases, lift the spirits. The bridges over the Seine in Paris, for example, affect people positively as there is a clear aesthetic appeal to these bridges individually and as an ensemble. There is evidence that efforts are being made in Canada to this end, including in the rehabilitation of our bridges. In the late 1990's for example, the Angus L. MacDonald suspension bridge in Halifax-Dartmouth was rehabilitated to add an additional traffic lane, bicycle lane and decorative exterior illumination to transform the bridge into a very definite landmark structure. This rehabilitation is an example of the recent trends within Canada to increase cyclists and pedestrian usage, along with positively affecting the response of the users and communities to the bridge.

Figure 9: Angus L. MacDonald, Halifax-Dartmouth

The Cummings Bridge in Ottawa Ontario is another example of the recent trend in Canada to restore the heritage value of a structure. In 1998, the structure was rehabilitated to accommodate wider sidewalks and a new bicycle lane, to add traffic calming measures, to maintain the lookout views, and to restore the heritage light fixtures and the ornamental handrails which were part of the original aesthetic of the bridge.

Figure 10: Cummings Bridge, Ottawa

THE ENGINEER'S PERSPECTIVE

Engineers are concerned with constructing a bridge that is functional, constructible, and satisfies current design standards. They are frequently mathematically-oriented and typically are not formally trained as to the importance of creating pleasing bridge aesthetics. During the early stages of an engineering student's studies at university, the emphasis is on theory and mathematics. There are few courses offered to teach future designers how to model and construct bridges, while at the same time considering the social and visual impacts of bridge design. Alberta has noted the importance of the engineering and architectural perspectives as follows:

> "The engineering approach to bridge design is often to consider a bridge as an abstract structural form independent of its surroundings. The architectural approach is often to integrate the bridge into the surroundings in spite of the shortcomings of the bridge's

structural form. A successful bridge designer must consider both the abstract structural form and the integration of the bridge into the surroundings."

Another perspective typically upheld by engineers is the notion of *form follows function.* This refers to the idea that good aesthetics are created through satisfying design that is both functional and efficient; the beauty is found in the flow of forces. Although some bridge engineers might appreciate the structural members of robust or industrial bridges and believe they are artistic, this notion is not always demonstrated, as for example by the typical precast concrete girder bridges. Although these structures are functional and efficient they are less than inspiring and do not typically enhance their setting.

Bridge engineers nevertheless tend to be very interested in the aesthetics of bridges and to have their favourites, such as the Brooklyn Bridge in New York, the Viaduc de Millau in France, the Severn Suspension Bridge in the United Kingdom, and other engineering structures such as the Eiffel Tower in Paris. They may be a bit suspicious about bridges such as the Alamillo Bridge in Spain, which is configured like a harp, or about the reverse inclined arch which characterizes a bridge such as the Mimico Creek Footbridge in Toronto. These bridges are not structurally natural configurations but they have other merits from an architectural perspective. Bridge engineers have tended to be very loyal to the idea that form follows function. Iindeed, they are driven in this direction by the exigencies of economy, as generally bridge owners wish to pay a minimum cost for their structures commensurate with an appropriate service life and reasonable maintenance costs. This approach gives rise to the modern highway bridge, the design of which is typically driven by cost and geometrical requirements. In some exceptional circumstances, and these exceptions are becoming more numerous as time goes by, other factors such as bridge aesthetics are considered to be more important and, to some extent, cost is a secondary consideration. In such cases, engineers experience somewhat more freedom than they are used to in terms of bridge concept and design, and the architects begin to show an interest.

This is not to say that bridges designed with cost as the primary driver do not have good aesthetics. They may well be very pleasing aesthetically from a mathematical perspective, and may combine economy and suitability for their function with a pleasing appearance. If, in addition, they can elicit a positive emotional reaction from passers-by, then they can certainly be judged to be a success from an aesthetic point of view.

When aesthetics are, however, a leading feature of the design process, the designer may be free to be more creative. The graceful curves of a small arch may, for example, be more pleasing to the eye than the typical low-cost steel girder. The designer may choose suspension bridge towers which have more texture and expression than the typical box-shaped towers which characterize many modern suspension bridges. In the case of smaller bridges such as footbridges, the designer's mind may turn to structural configurations which in a low-cost environment would be considered inappropriate. An example is the footbridge connecting the Royal Opera House with the Ballet School at Covent Garden in London, England.

Figure 11: Bridge at the Royal Opera House, London, England

ARCHITECTURAL PERSPECTIVE

Architects tend to approach bridge design quite differently. Their training causes them to be typically more interested in emotional response, the consideration of space and context, and the effect of material selection, texture and colour. Their tendency is to consider scale and proportion from a visual perspective which can be adjusted to suit circumstances, rather than a mathematical perspective which generates scale and proportion as a consequence of typical engineering considerations such as the economical use of materials and the ease of constructability. Architects will talk about the opportunity for celebration which a bridge crossing may present, for example.

Engineers and architects collaborating together on a bridge, therefore, have to learn a common language and to experience some back-and-forth during design development. Architects may learn that their favourite bridge ideas are totally impractical, and engineers may find out that the architects can actually suggest improvements to their schemes. In the end, though, the final product should be better. We think this has been the case when we have, as bridge engineers, collaborated with architects to produce designs for structures such as the Humber River Footbridge in Toronto, the proposed Springbank Park Footbridge in London, designs for the St. Patrick Footbridge competition in Calgary, and the new Strandherd Armstrong Rideau River Bridge in Ottawa.

Figure 12: Proposal for St. Patrick Footbridge, Calgary

Another example of such collaboration is the replacement of the Sir Ambrose Shea Bridge in Placentia, Newfoundland. The existing bridge is a structural steel lift bridge constructed in 1963. This is a bridge with virtually zero aesthetic appeal. Engineers and architects drew up a number of schemes for its replacement, including swing bridge, bascule bridge, and lift bridge schemes. Lift bridge schemes included ideas reflecting the existence of various fortifications in and around Placentia giving rise to one very preliminary scheme which was rather reminiscent of Tower Bridge in London.

Tower Bridge was, of course, developed in the context of the existence of the Tower of London on the riverbank nearby, and at the Sir Ambrose Shea Bridge both British and French forts existed immediately adjacent to the site and the fortification at Castle Hill nearby is a recognized historic site. A bridge somewhat reminiscent of Tower Bridge, therefore, has some reasonable context in Placentia.

Another element of context at Placentia is the sea and the life of the sea including sailing and fishing. The vocabulary of ships, therefore, was another reasonable language in which to address the development of a scheme or schemes for this replacement of the old lift bridge. Some inspiration in this regard was drawn from the new lift bridge at Salford Quays in Manchester, England, which similarly expresses the language of the sea in its basic configuration and architectural expression.

Figure 13: Lift Bridge at Salford Quays, Manchester, UK

Architects in general tend not to see bridge design as an object-oriented process. Bridges are elements that exist within a surrounding context and, in that place, they must look and perform well, balancing the positive social impact and visual quality with the technical rationale and functionality of the design.

Looking back through history, one can see that architects in charge of bridge designs sometimes focused on the integration of the notions of firmness, commodity and delight. With the industrial age, the design of bridge became the domain of engineers, where the focus area was changed to utility and simplicity driven by economics.

Although bridges are often seen by engineers and the general public as utilitarian instruments that span irregular situations in a regular and organized way, architects tend to focus on incorporating more aesthetic qualities, historical references and sometimes playfulness into bridge designs.

Bridges, due to their scale and solidity, will have a significant effect upon their surroundings and context. Large scale elements that are not beautiful have the power to easily damage a site, but where they are successful, they create opportunities for celebration and social significance, as in the case of the new Winston Street Overpass in Burnaby, British Columbia.

Figure 14: Winston Street Overpass, Burnaby, BC

Architects focus on the planning of the space into which the bridge will be built, the bridge programming to facilitate the journey, rather than the transportation experience alone. They may like to consider the bridge as a connector, and a catalyst that establishes new opportunities for development, for nodes of activity, for vistas, gateways and destinations.

Architects hold two major tenets in bridge design: the object-oriented view, and the holistic notion. The first perspective, the object-oriented approach, encourages the design of the bridge itself as a sculptural element where the scale, proportions, texture, color and materials are all tailored into a design solution where art and science meet and the architecture demonstrates the connections amongst the aesthetic qualities, details and decoration, with the engineering and mathematical aspects of the design.

The holistic architectural approach to bridge design considers the bridge more as an abstract structural form. It celebrates the stunning structure that would or could harmonize with the scenic landscape or augment the uniqueness of the context characteristics. From this approach some remarkable bridges have been created in recent years. Some engineers and architects may consider such bridges to be frivolous, but we suggest that there is a special place for them in a complex world which thrives on diversity of expression.

Figure 15: A Unique Structure Appears: Alamillo Bridge, Seville, Spain

AESTHETICS AND FUNCTIONAL DESIGN

Pleasing aesthetics can be compromised when a bridge designer does not consider the human factors of bridge design including the setting the bridge will be placed in and the visual and emotional influence it will have on the community. The extensive public involvement in the design process and the way the bridges interface with the people who use them (universal accessibility for footbridges, cycling lanes, landscaping, and signalization priorities) may help to ensure that good aesthetics are considered. A community is often aware of the negative effects unsightly or industrial structures can have on society.

The talented designer will strive to interpret the aesthetic concerns and notions addressed by the public and amalgamate them with a functional design.

The visual influence a bridge has on a society is the result of the type and form of the structure, the selection of materials, and its relationship to the existing site. The characteristics of elegance, simplicity and function in a bridge structure can be achieved by selecting a creative designer with the ability and ingenuity to successfully create an appropriate structure to suit the surrounding environment. This can be illustrated by several bridges including the Humber River

Arch Bridge in Toronto, and the Strandherd Armstrong Bridge in Ottawa which is now under construction.

Figure 16: Strandherd-Armstrong Bridge, Ottawa

THE ADDITIONAL COST OF AESTHETICS

Small landmark or signature pedestrian bridges often do cost more to create outstanding aesthetics. Such bridges may cost more as they typically require specialized contractors, materials, and fabricators, and involve input from architects, urban designers, artists and landscape architects. When evaluating the cost of outstanding aesthetics in larger bridges the issue is transferred from the additional costs associated with aesthetics to the comparison of different structures providing varying degrees of visual appeal. When aesthetics are considered at the beginning of the design process instead of as an afterthought, additional costs can often be all but eliminated.

There are a number of traditional definitions of aesthetics. If one imagines aesthetics in the context of dancing by Rudolf Nureyev and Margot Fonteyn, one thinks of a visual appeal augmented by the music of the ballet to engender an emotional response and a sense that one is in the presence of true beauty. Similar responses are, or can be, created by works of art and, indeed, museums around the world are devoted to such objects. A high order example is Bernini's *Apollo and Daphne*. We can reach out to the churches for examples of architectural art which includes the highest order of aesthetic affect, such as St. Peter's in Rome, the Blue Mosque in Istanbul and St. Paul's in London. In Canada, there are only a few such delights, but

they include the BAPS Shri Swaminarayan Mandir Temple in Toronto and, we suggest, the CN Tower.

Bridges also have the potential to appeal to the emotions from an aesthetic perspective, creating a sense of wonder, of awe, of surprise, of calm and of admiration amongst other emotions. Examples include the Confederation Bridge between New Brunswick and Prince Edward Island. The Quebec Bridge definitely creates an impression of power and stability, given its massive scale. This is to be expected as this was created in the wake of the Tay Bridge disaster in Scotland which led to the design rules incorporated in the Forth Rail Bridge near Edinburgh, and of the original disaster which befell the first attempt to span the St. Lawrence River at the Quebec Bridge site. The result is the current Quebec Bridge, a structure which gives every appearance of being impervious to any imaginable load. A delightful bridge such as the Bank Street Bridge over the Rideau Canal in Ottawa is pleasing to the eye and creates a tranquil mood, as does the Broadway Bridge in Saskatoon on a much larger scale. Another bridge with interesting aesthetics is the International Bridge at Cornwall which seems so high and narrow as to excite some wonder as to how it manages to sustain wind loading, whereas bridges such as the Lions Gate Bridge in Vancouver and the Thousand Islands Suspension Bridge In Ontario create the impression of workmanlike functional design with all due attention to economy.

At the far end of the aesthetic scale are the typical highway overpass bridges which are driven almost exclusively by low cost and practical considerations.

In this overall context, one can discuss the additional cost of good aesthetics. Our thesis here is that good aesthetics basically cost nothing. Bridges are essentially utilitarian structures but, because they are in many cases dominant in the landscape, they should have an appropriate emotional appeal depending on their intended purpose. Generally they should be honest expressions of that purpose and, if they satisfy that goal and are created by designers with some artistry, good aesthetics should follow. They may not be overly impressive every time, as a quiet, subdued bridge may be more appropriate in a pastoral landscape as is the case of the Elora Gorge Bridge in Ontario. Grand bridges such as the Golden Gate Bridge in San Francisco seem to satisfy this criterion in the context of a monumental site, something it has done so successfully that most people think of the Golden Gate as a bridge whereas, in fact, the Golden Gate was there long before the bridge and is the waterway over which the bridge now passes. The Golden Gate itself, of course, was created by the setting of the sun over the Pacific. The selection of the colour of Golden Gate Bridge, however, clearly was related to its name and contributes immensely to its appeal without any additional cost. Somewhat the reverse can be observed at London Bridge where the multi-span arch bridge designed by John Rennie now finds itself in Lake Havasu City in Arizona where it looks somewhat anomalous, and its replacement over the Thames in London is a totally nondescript, unremarkable structure from the experiential perspective. No one pays much attention to London Bridge any more, unless they are in Arizona, an unhappy development for London.

There are, of course, at least two issues which suggest that aesthetics cost money. One of them is bridge decoration. There are, however, many decorated bridges in the world which are very successful and which have met with a positive response from passers-by over the years. Very few of these are in Canada, but one can be found in Peterborough, Ontario, where the longest unreinforced concrete arch in the world was built in the 1920s. This is the distinguished Hunter Street Bridge. The additional cost of decoration here must be very small compared to the increased aesthetic appeal and noteworthiness which it imparts to the bridge.

Figure 17: Hunter Street Bridge, Peterborough

Another example of decoration is the thunderbird motif built into the upper lateral bracing connecting the two arches of the Humber River Bridge in Toronto. Its decoration is nothing more than additional steel plates which were suggested by the artist who was part of the design team. Although they were relatively minor physically, they have a very large effect on the appearance of the bridge, and they have a meaningful cultural connection to the site as it was for centuries a camping and setting-off point for First Nations people travelling by canoe.

It is a common perception that architects may invent impractical bridge configurations which the engineer is then left to struggle with, and which cause additional cost to be incurred. There are certainly examples where this appears to have happened, for example on a footbridge in Portugal which has a sideways offset step at mid-span. There is no practical reason for doing that and it certainly created problems and incurred additional cost. One would not want to do that very often but, on the other hand, it was an interesting experiment.

SIGNATURE BRIDGES

There are very few bridges in Canada that are popularly characterized as signature bridges, that is, bridges that bear the unmistakable imprimatur of a specific individual bridge designer. The most recognizable signature name in bridge engineering and architecture currently is Dr. Santiago Calatrava and, indeed, there is one small bridge designed by Dr. Calatrava and engineered by Vic Anderson, the Mimico Creek Footbridge in Toronto. Dr. Calatrava's signature can readily be seen there, even in comparison with a completely different type of structure, the BCE Galleria which he also designed. While it could be said that Dr. Calatrava's work is much imitated, it is perhaps fair to consider that he is the source of inspiration for many bridge designers. An example is the proposed new Strandherd-Armstrong Rideau River Bridge in Ottawa, which is inspired by Dr. Calatrava's Lusitania Bridge at La Merida in Spain. It can be

argued that the new reality of importance of bridge aesthetics, and even of bridge work as art, has been strongly influenced by Dr. Calatrava's work which, in turn, is facilitated by modern electronic computational capabilities.

Other important examples of signature bridges elsewhere include the Golden Gate Bridge, a project associated with Joseph Strauss but actually designed by Charles Alton Ellis; the Brooklyn Bridge designed by John Roebling; the Mackinac Straits Bridge designed by David Steinman; and the Pont de Normandie and the Viaduc de Millau designed by Michel Virlogeux. A recent example with a Canadian aspect is located in Chicago where the new BP Bridge was designed by Frank Gehry.

There is nothing really new about signature bridges but there is probably an increased willingness, and even enthusiasm, for such bridges in the context of an increased awareness of aesthetics and a willingness to invest, from time to time, in an exceptional and sometimes very personal design.

VALUE TO SOCIETY

Bridges located in historic sites, urban settings, significant and influential places and areas of high visibility with a large audience can have a significant effect on a society. They have the potential to;

- Create a pleasing and safe environment which can attract new business and essential services to the area
- Enhance the mental and emotional well being of society, uplifting the spirit and uniting individuals through community and country pride
- Attract tourism and bring individuals to a new area or restore heritage in an older place
- Hold in time the current design and culture practices and sustain them for a long duration
- Create a community gateway and brand identity for the structure, the client and the neighbourhood, city, or country
- Inspire future generations of engineers, architects, contractors, and fabricators

Bridges often dominate a landscape. When placed in an urban setting, they can either create a positive impact for the communities around them or degrade the social environment. In part because of increased public attention on built form, the future direction of bridge design needs to focus to a significant degree on the human factors of design, to optimize value to society.

BLENDING WITH THE ENVIRONMENT

One often hears the statement in the context of design parameters and competitions that a proposed bridge is to "blend with the environment". We suggest that this could be considered an unfortunate turn of phrase in the context of bridge aesthetics. It may be considered, for example, that antique stone arches can be harmonious with their environment, particularly in rocky or mountainous terrain where natural stone is evident as a feature of the landscape.

Similarly, a timber bridge in forested terrain may achieve harmony with its surroundings. Exceptional steel and concrete bridges can achieve a harmonious effect in the urban environment, although all too often they degrade it. A small bridge which is judged to have succeeded in fitting in quite well with an urban environment is the Corktown Footbridge in Ottawa. The elevated expressways in Montreal and Toronto are structures which lack visual harmony with their urban environment, yet they provide extremely useful and, indeed, critical service in the transportation network.

Many other bridges do not blend into the environment whatsoever and yet they were considered quite successful. Bridges such as Calatrava's Roche-sur-Yon Footbridge in Paris which is found in a railway environment and, on a larger scale, the Whirlpool and Rainbow Bridges across the Niagara River can hardly be considered to blend with the environment, but rather are a dominant feature of it. Other structures such as Centre Pompidou in Paris, the Eiffel Tower, the Pyramids, and Sydney Harbour Bridge really do not blend with the environment and, in many regards, are not harmonious with it, and yet they are all universally admired structures. Similarly, bridges such as Lions Gate Bridge in Vancouver, the Pierre Laporte Bridge in Quebec, the Jacques Cartier Bridge in Montreal and the Thousand Islands Bridge from Ontario to the USA all have, in each case, a certain aesthetic appeal, and stand out dramatically rather than blending in with the environment, in the same way that Rodin's *La Danaide* has obvious merit irrespective of whatever room she is placed in.

With the input of engineering, architectural and artistic perspectives, bridges may, given current technology, materials, computing capability and contractors' skills and resources, seek to improve the environment rather than be lost in it or to wear a metaphorical camouflage. Successful bridges may, in fact, improve the environment, contributing to the social wellbeing and happiness of passers-by who may regard it with wonder or interest and find it, if it is a small stone arch in the forest, to be peaceful and thought-provoking and, if it is an ultra-long suspension bridge, to be thrilling and wonderful. In such cases, we suggest it can probably be calculated that a bridge has a net positive overall environmental effect.

LEARNING FROM EUROPE

In 1997, Spain built a $228.3 million modern art museum called the Guggenheim Museum Bilbao. The most interesting aspect of this facility, even more than the abstract structure itself, was the location where it was built. It was constructed in a third or fourth tier city that had high unemployment rate, and many other problems; including businesses leaving the area, urban deterioration, and a poor public transportation system. The government was dedicated to improving this area and they saw the Guggenheim Museum as a part of the solution to the restoration. Prior to the construction, as part of a holistic solution, the city created a new subway line, waterfront, new drainage and water/air clean-up systems and additional culture investments along with other improvements.

The end result of the above improvements was an 800 percent increase in visitors to the area, hope restored to the citizens, the creation of 907 new full-time jobs, and a large inflow of cash into the local economy. As well, due to the Museum's success, the $20 million invested in its endowment when it opened has since been increased to $118 million dollars.

The "Bilbao Effect" does not prove that the Guggenheim Museum was the solution to restore a city and clear it of violence; what it does demonstrate is the impact a structure can have when combined with other infrastructure investments. The addition of a major attraction must be

accompanied by other developments and improvements to the city, such as enhancing the waterfront, and adding cultural centers, to successfully restore or enhance a society.

When a country invests in building interesting and aesthetically pleasing infrastructure the impacts on the society can be large. As demonstrated by the “Bilbao Effect”, the impacts ripple through society as unemployment is reduced, crime is reduced, communities are united, and money is infused into the local economy through attracting tourists and new business to the area.

Figure 18: Bilbao Guggenheim Museum, Spain

DESIGN-BUILD AND AESTHETICS

As Alternate Financing Procurement (APF) and Public Private Partnership (PPP) project delivery methods are increasingly used to design, build and maintain infrastructure, the impact on bridge aesthetics becomes more complicated and difficult to ensure. In the case of a Public-Private-Partnership, if the performance specifications and the reference design tender package do not very clearly define that the structure must be visually appealing, there are no guarantees that this will be achieved. It is also very difficult to quantify this aspect of design.

Before selecting the Public-Private-Partnership delivery method, a screening phase is often used to determine if the method will benefit the taxpayer and meet with public approval. The design criteria are specified by the owner or governing body and the private consortiums tendering to win the project will be selected based on the owners’ assessment of their proposals. Careful costing of options allows for signature bridge ideas and iconic structures to be accurately analysed and to be accepted or rejected at the early stages of the design process.

DESIGN COMPETITIONS

Design competitions play a large role in bringing creativity, innovation and ingenuity from design firms of all sizes to create both iconic and aesthetically pleasing structures. Design competitions tend to attract a large number of engineering and architectural firms that are attempting to raise the profile of their firms and gain recognition in the design of signature structures to showcase their best talent and ability. The design competition format usually provides owners with increased profile for their project and increases its marketability and often fundraising potential.

Design competitions are not new, an example being the competition for the design of the new bridge over the Avon Gorge at Bristol, England in 1830. Design competitions are now fairly commonplace, a recent example being the competition for the design of the new St. Patrick Footbridge over the Bow River in Calgary. These competitions can potentially be inefficient as people generate schemes that are never built, but they do have the advantage of allowing creative people to exercise their minds relatively free of constraints and to propose whatever scheme occurs to them. The St. Patrick Bridge competition elicited a range of schemes from the elegant to the impractical. It is the nature of design competitions that many entrants are disappointed as their schemes are rejected. The great thing about them, though, is that anyone can enter and one never knows who will win. Very often in competitions of this type, aesthetics are the key feature in the judging of the competition entries. Unappealing designs almost never win.

COMPUTERIZED DESIGN

Computer modeling has created limitless opportunities for designers, owners and the public to explore and test ideas through virtual simulations. Both design and construction techniques can be evaluated for the rehabilitation of existing structures and the design of new obscure structures. With finite element modeling there is no limit to the possibilities of structure types and designs. The Sheikh Zayed Bridge in Abu Dhabi designed by architect Zaha Hadid is a bridge that pushes the limits of architecture and proves there are apparently no practical boundaries. This twin deck prestressed concrete box girder bridge demonstrates the capabilities of computer analysis and the ability to make innovative designs like Zaha Hadid's creation, a reality.

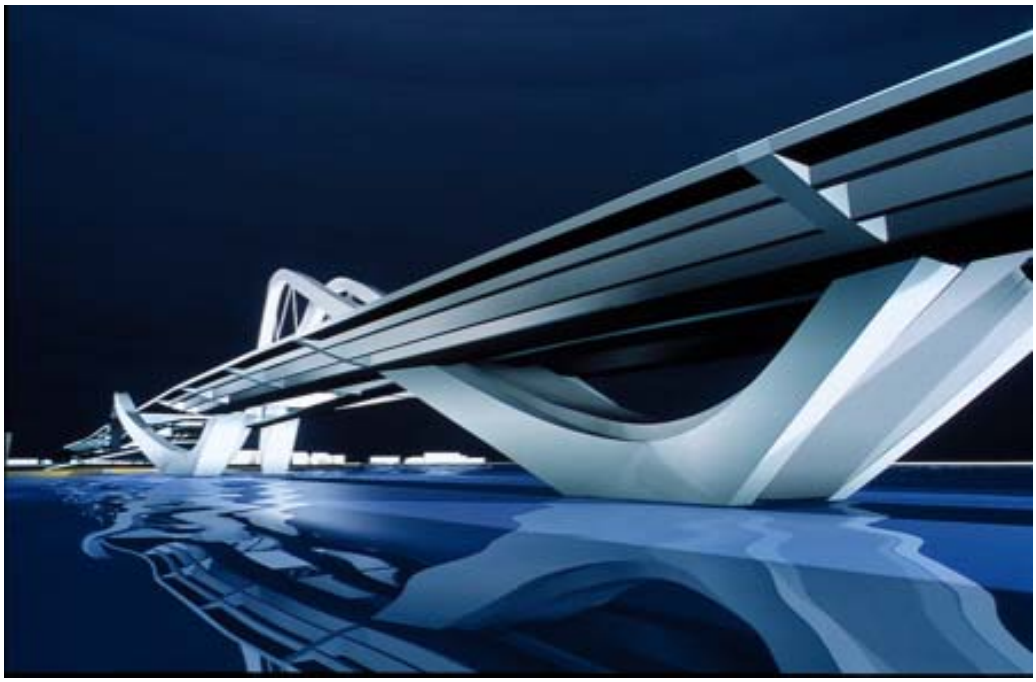

Figure 19: Sheikh Zayed Bridge, Abu Dhabi

Another example of computer model capabilities is the launching of the Kicking Horse Canyon Bridge. The erection of the bridge consisted of launching large steel girders high above a

canyon valley on a curved trajectory. Accuracy and reliability were essential. With advanced computer modeling this was possible.

Figure 20: Kicking Horse Canyon Bridge, Kicking Horse, British Columbia

As computers advance and as software and modeling capabilities expand the potential for varying designs becomes limitless, the epigram “the sky is the limit” may no longer apply. Some thoughts on the future direction of structural analysis and modeling behaviours include the ability to evaluate an image, rendition or a sculpted model to determine the stresses and strains in each member.

CONCLUSIONS

The review of past trends and current practices in Canada suggests that there is an increased awareness of pleasing bridge aesthetics. With many provinces leading the way to improve the visual impact of infrastructure, there is an overall appreciation for good aesthetics and their influence on society. This is demonstrated by the examples across Canada and overseas including the modernization of the Angus L. Macdonald Bridge Nova Scotia to include visually pleasing illumination; the implementation of the Esplanade Riel Bridge in Winnipeg; and the rehabilitation of Lions Gate Bridge in Vancouver, to name just a few examples. The richness of a high quality design can be sought through a creative design team with solid and imaginative experience in structural design combined with the potential to integrate the structures into their social and natural settings in a positive manner.