Optimizing Large-scale Transportation Infrastructure Projects using Building Information Modelling

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New bridges are large investment projects that have long-term significance. In Montréal area, such a project is underway in the form of the new Champlain Bridge. Use of traditional design, scheduling, and process management methods is expected in this project. Whereas such an approach has major drawbacks/limitations: scarce resources in current economy; lack of assurance of long-life design; missing the detailed analysis of the effects on environment; lack of automatic structural design changes in response to other decisions; and only limited capabilities to visualize and adapt the design, processes, and flows of the project. Recent advances in Building Information Modelling (BIM) provide robust, consistent, and complete answers to these issues. In this paper we develop a BIM based model for the new Champlain bridge project. The proposed model is a 5D model that includes 3D visualization, scheduling, estimation, and facility management. We analyse 12 different design scenarios proposed by Infrastructure Canada for this project and demonstrate the efficiency of BIM against the traditional approaches. To our knowledge this is the first time that BIM has been used in Canada for a large-scale bridge project.

1. INTRODUCTION

Building information modeling in past few years has seen a significant development in the fields of architecture, engineering, and construction (AEC). Moreover, the use of BIM in the fields of civil, mechanic and electrical, etc. projects is becoming more common. BIM is not restricted to only 3-Dimensional (3D) view, but it also incorporates higher dimensions: 4D Schedule, 5D Cost Estimation, 6D Facilities management, 7D Sustainability, and 8D Occupational safety and health. BIM is capable of maintaining the project implementation at the highest level of quality, and it allows architects and engineers the ability to predict the performance of projects in different scenarios before their implementation. It can improve the design, design change, imagination or conception, design analysis, simulation, speed-up and facilitation of critical information availability, and provide the highest projects quality. Therefore, we envision the BIM to have a high level of applicability in the large-scale engineering infrastructure projects, especially in the transportation projects.

BIM is a process for optimization of the lifecycle of the infrastructure projects starting from the design process, to implementation, and then to the end of the delivery process. However, there are several challenges faced by BIM such as, high cost of software/hardware, concerns about responsibilities, legal dimensions, etc. BIM has an immense impact in reducing the problems that are related to project implementation, before and after e.g. cost and quality that are considered of significant importance to the decision makers, whether public (government) or private (business or individual).

Building information modeling as a program has been applied in several activities, like occupational health and safety, planning, constructability analysis, and operation of construction machinery. According to the studies that have been conducted on application of building information modeling, an immense positive impact on the projects has been observed. These impacts include: better familiarity of the project problems before the implementation; reduce project cost; speedy delivery; etc. However it has been observed that BIM requires improving 3D visualization, project management, and facility management.

The aim of this research is to demonstrate the utilization of BIM in a large-scale transportation infrastructure project. Specifically, we present the development of BIM process for the new Champlain Bridge, which is to be built in next few years over Saint Lawrence River in Montréal. We have used the initial Request For Proposal (RFP) documents issued by infrastructure Canada to develop the detailed model and have shown the extent of benefits and impacts of using BIM in the feasibility study, project implementation, and project delivery. We also compare the performance of BIM with the use of conventional project management approaches. The rest of the paper is organized as following. First we present a detailed review of the current literature related to BIM. We then present the methodology adopted in this research. The implementation of BIM for the case study of new

Champlain Bridge is explained. We then analyse and discuss the results of the implementation. In the end we discuss our conclusions and the future direction of this work.

2. LITERATURE REVIEW

The beginning of engineering and architectural drawing was, as we know the "Freehand" drawing. It was the traditional method since the beginning of the emergence and continued until 1960s. But since then, due to the advent of computer age, there has been a significant change in the engineering and architectural drawing (1). 1960 is considered the beginning of the new technology called Computer Aided Design (CAD). This technology led to change the world in terms of speed and accuracy of engineering and architectural drawing. In the beginning CAD was a 2-Dimension (2D) visualization technology. Then in 1970, CAD advanced from 2D to 3D modeling and several commercial software such as, AutoCAD, Archicad, Sketchup, etc. became available (2). These 3D CAD technologies continued to develop until 1990s. Another significant development in CAD technology was introduced in 199os when higher dimensions were introduced and a consistent modeling of buildings were introduced in the form of Building Information System (BIM). Several commercial software were developed, including: AllPlan, Revit, AutoCAD, Archicad, Sketchup, etc. The aim of BIM was defined to improve the lifecycle of projects from the beginning at the design process to the delivery of the project. Furthermore it was envisioned to aid the owners and decision makers to see all project stages (e.g. construction planning, schedule, cost estimation, etc.) in detail, before implementation (3).

(4) defined the Building Information Modeling as a process to integrate all information related to the infrastructure construction project in one consistent model. BIM not only support architects to design the form and aesthetics of the infrastructure, but also is a model to support engineers to design and analysis the structure and components of the infrastructure. Furthermore, it is a tool that can be used to optimize the project's life cycle and processes; easily predict the performance of project in the design period before implementation; and most importantly figure out the problems and project risk before implementation with high level of accuracy. The detailed information generated by BIM can describe the project cost, required resources,

their availability schedule, time of the project delivery, etc. BIM also supports simulation and visualization, which can describe the scheduling process by animating the implementation stages of project from the beginning of the design phase to the delivery of the infrastructure (5). Another explanation of the BIM stated in (6) is: *"Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition".* Figure 1, describes the various project stages that can be modelled and simulated in the BIM.

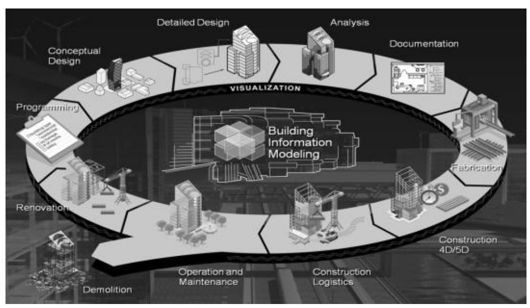


Figure 1: The BIM lifecycle for project stages (7)

For the consistent exchange of information a standardized model called Industry Foundation Classes (IFC) was introduced by International Standards Organization "ISO" 10303 (8). This system has been established since 1994 by the Autodesk and has been used as industrial standard since 1996 (9). IFC is a process to transfer the information or data among the engineers, owners, designers, general contractors, subcontractors, and vendors, etc. as well as exchange information or data between nations (10). Figure 2 shows the widely available support of IFC model in the industry. Without IFC the sharing of information within BIM and across various BIMs will be very difficult. Therefore, this system is supported by more than 150 software, including: AllPlan, Neviswork, and Revit, etc. (11).

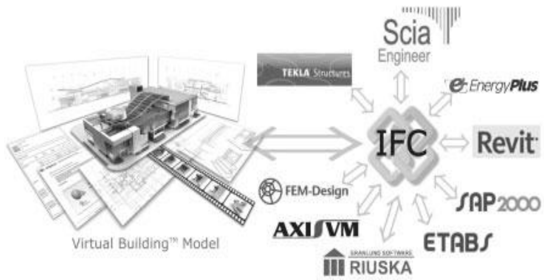


Figure 2: The IFC support (12)

3. METHODOLOGY

The goal of this research is to demonstrate the benefits of using BIM for design and feasibility studies of large transportation infrastructure (e.g. bridges and freeways) projects. As a case study the new Champlain bridge project is considered. In this paper we focus on the three levels: 3D visual, 4D schedule and simulation, and 5D cost estimation. These dimensions are developed according to the RFP on the new Champlain Bridge that is made available by the Infrastructure Canada. Finally we will analyse the developed BIM system for the design of the new Champlain Bridge by using AllPlan software for 3D modeling, Nemetschek Engineering software 4D schedule and simulation, and Microsoft Excel for 5D cost estimation. Figure 3 shows the steps that are followed to develop the BIM system, while figure 4 shows the pyramid nature of the developed methodology. We describe the process of development of each dimension as following.

3.1. 3D modeling

3D visualization provides the basis for the higher levels of BIM levels e.g. 4D schedule and simulation, and 5D cost estimation. 3D modeling can help owners, engineers, and contractors to make quick decision on form and aesthetics of the project, as they can manipulate the highly realistic rendered 3D model. Moreover, this model is supported by CAD software used by engineers, such as Revit, Autodesk, AutoCAD, ArchiCAD, Tekla, AllPlan, etc. 3D model is actively used in the design of roads, bridges, and buildings for quick changes and evaluating their effect of the architectural designs. For example, if one wants to change the dimension or remove a column they can do that very quickly in the

2D or 3D model, and then the software can automatically update the project. Furthermore, during the design phase 3D model allows to choose the materials types that may depend on the type of units and country's codes. Detailed reports on the project and highly rendered models for visualization are available in various formats including interactive pdf file format. Furthermore, the 3D model allows exporting the project data to the IFC data standard.

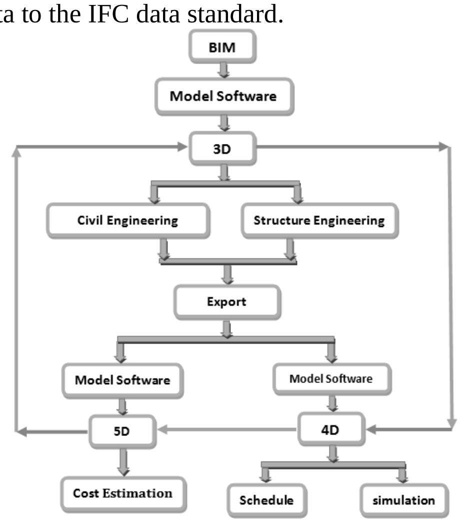


Figure 3: Flowchart of BIM

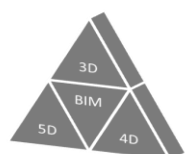


Figure 4: Pyramid methodology

3.2. 4D Modeling (Schedule & Simulation)

4D modeling is the part of implementation of the project processes that is based to the 3D model. So, the scheduling process takes place after the completion of the 3D model of the project design. Once 3D model is completed, the model is exported using IFC standards to develop the 4D modeling in the schedule module of BIM software. 4D model helps the owner and contractor to figure out detailed estimates at any time during the project implementation phases from the beginning to project delivery. Moreover, 4D support a simulation by creating an animation from the software like, Naviswork, and Nemetschek Engineering. Using these interactive animations one can observe the project implementation from the beginning until end of the delivery. The scheduling module of BIM is able to detect clashes and inconsistencies. For instance, in the 4D BIM, one can investigate whether two or more structures would intersect with each other, before implementation in design time. Thus resolving the clashes without losing time and cost overflows.

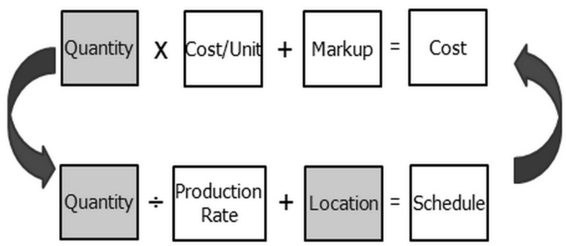


Figure 5: 5D Cost Estimation (13)

3.3. 5D modeling (Cost Estimation)

5D modeling is a process that comes after the scheduling and is based on the 3D, and 4D modeling. This process is achieved by exporting the quantity takeoff, using IFC model to software modules such as, Nemetschek AllPlan, and Microsoft Excel. The costs are determined based on the unit prices and then this information is exported to the Microsoft Excel or other software that support 5D. Finally, after process completion a detailed report on all units and total project costs can be analysed. The cost calculation process in the 5D model is shown in figure 5. Please note that for this study, we have restricted the scope to 5D only and the higher dimensions of BIM are not considered.

4. CAUSE STUDY

We chose construction of the new Champlain Bridge over Saint Lawrence River in Montreal as our case study. This is one of the biggest transportation infrastructure projects in recent history of Canada.

4.1. Existing Champlain Bridge

Champlain Bridge is considered part of an important transportation link between Canada and USA. The original Champlain Bridge was constructed in 1962, but in recent years, experts have discovered that there are cracks in the bridge that may threatens a collapse. Canadian government thus decided to build a new Champlain Bridge that will have a life span of 125 years. It will have increase lanes and will also take into account the problems that the old Champlain Bridge suffered. The existing Champlain Bridge consists of three lanes in each direction. One of these lines is reserved for buses at peak times in both directions. The length of this bridge 3.44km and the long span is 215.5m, and the construction cost of this bridge was C$ 52 million (14). Champlain Bridge is currently experiencing higher congestion compared to other bridges connecting Montréal Island to rest of the area.

Figure 14 view for existing Champlain Bridge (15)

4.2. New Champlain Bridge

A new Champlain Bridge is considered a large investment project that will provide enormous economic income in the future. It is a major part of the trade corridor between Canada and United state, as well as important for the commute of local population. According to the studies on a new Champlain bridge by Infrastructure Canada, it is expected that traditional methods to design and project management would be used. These methods may generate problems in the design, scheduling, and process management. This approach may leads to lack of assurance of the long-life design, high level of accuracy, and consistent information availability (16)

4.3. BIM System

As mentioned earlier, here we developed a BIM system for the new Champlain Bridge. Our focus here is to develop a BIM system that is is focusing on 3D model as the foundation for BIM and models of 4D schedule and simulation, and 5D cost estimation. We used AllPlan for developing the BIM system. Figure 24 shows the lifecycle management of project by BIM system in AllPlan.

Figure 24: AllPlan lifecycle for project stages (17).

4.3.1. 3D modeling

The 3D modelling capabilities of AllPlan were used for the quick development of the model. It provides easy modifications and changing of unit without any inconsistencies. For example, if you want to change or delete some columns you can do that on the 2D or 3D plan, and then the software automatically will change the modifications in rest of the project. At the design time you are allowed to choose the materials types that depends to the type of your unit and your country codes. Moreover, AllPlan support 3D PDF, which is most important to help the owners, contractors to figure out all details without resorting to download the expensive software. This file can provide project details such as, sections, view, etc.

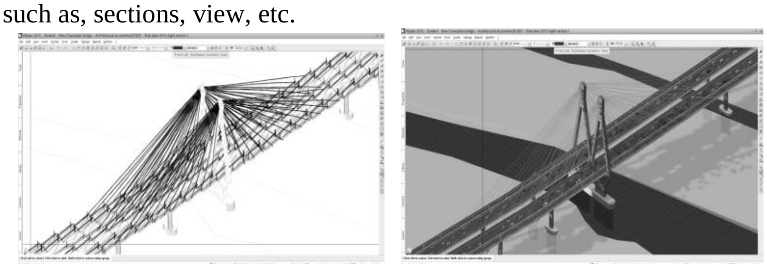


Figure (20) 3D Champlain Bridge, sketch preview(left image), rendered model (right side)

AllPlan can provide reports on project details in a few minutes and can export as a PDF, Word, and Excel, as shown in figure 22.

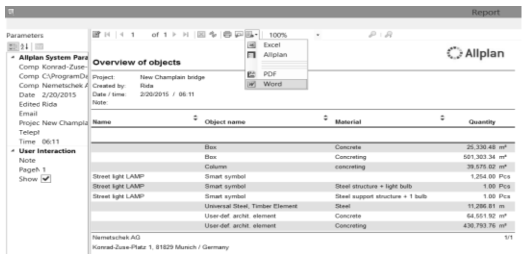


Figure (22) AllPlan Report Generation

4.3.2. 4D Modeling "Schedule & Simulation"

Based on the 3D model developed in AllPlan, a 4D model was developed using Nemetschek Engineering. Such model can estimate the schedule and simulate it in form of an animation. This model helps the owner and contractor to figure out, at details related to time of the project implementation phases, from the beginning to project delivery as shown in figure (24). Moreover, the owners, engineers, and contractors they can observe the project implementation from the beginning until end of the delivery using animations as shown in figures (25, 26,27 and 28).

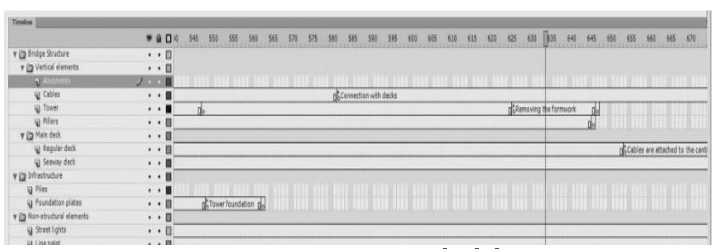
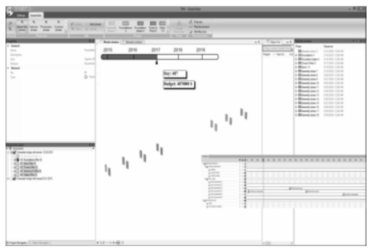


Figure 24: Project schedule



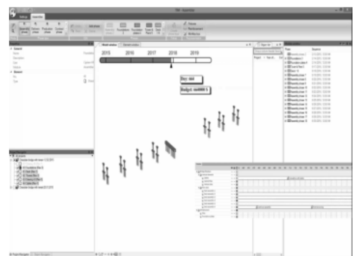
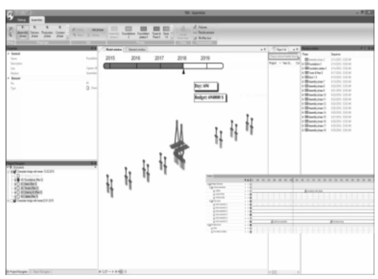


Figure 25: Project implementation "Day 487" Figure 26: Project implementation "Day 664"



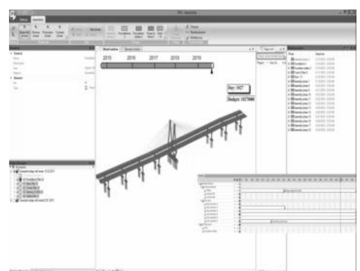


Figure 27: Project Implementation "Day 694" Figure 28: Project implementation "Day 1027"

4.3.3. 5D modeling " Cost Estimation"

5D modeling is a process come after scheduling and this process is based to the 2D, 3D, and 4D modeling. This process is done by exporting the quantity takeoff to a spreadsheet, where the unit prices are determined for the project, and then the information exported for presentation. Finally, after the completion of calculations detailed report for all units and the total of project cost are developed. An example of such process is shown in figure (29).

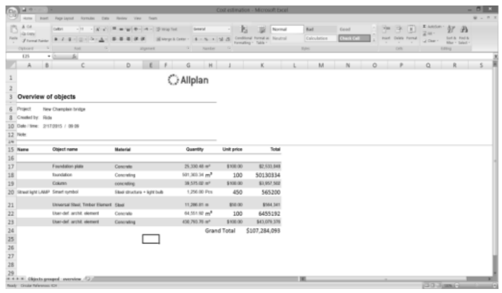


Figure (29) 5D Cost Estimation Microsoft Excel

5. ANALYSIS

We developed comparison between various proposed designs suggested in the Request for Proposals published by the Infrastructure Canada for new Champaign Bridge. The details of which are shown in the table 1 and 2. Analysis is performed based on prices, as well as various other different advantages and disadvantages. At the moment, it should be noted that the exact design and details of the bridge are not finalized so, our implementation of the BIM is only based on assumptions about them. Table 3 represents the comparisons between traditional and BIM system. Using BIM analysis our initial conclusions in Table 4, figure 31, and 32 suggest that cable-stayed bridge design scores the highest and is the most favourable option.

Criteria	Concrete single box	Hybrid steel-concrete	Composite Superstructure bridge for twin girders and boxes	Composite Superstructure bridge with V shaped	Cable-stayed bridge
Length / width	The total length of these bridges are 3.5KM, and length seaway span are 200M while the regular span are 80M and the deck width in both directions are 23.82M				
Description – Seaway	Single box of prestressed concrete or a composite of steel and reinforced concrete this option built by balanced cantilever(18)	This model is combination of concrete and steel, as is the case in the existing bridge	This model of seaway depend to the composite pillar	This model of seaway depend to the composite pillar on shaped "V"	The seaway depend to the cables that are composite on single tower
Description – regular spans	Made of prefabricated concrete	Made from prefabricated concrete or composite construction	The regular spans are composite construction	The regular spans are composite construction	The regular spans are composite construction
Construction constraints	constraints this model is to work for a short period frequently on the seaway	constraints this model is the seaway closed in the installation span	constraints this model is to work for a short period frequently on the seaway and A closed box-girder it will lead to the cancellation corresponding constraints.	constraints this model is to work for a short period frequently on the seaway and A closed box-girder it will lead to the cancellation corresponding constraints, and the seaway closed in the installation span.	constraints this model is to work for a short period frequently on the seaway and A closed box-girder it will lead to the cancellation corresponding constraints, and the seaway closed in the installation span.
Construction cost (with contingencies)	The cost of this proposal is 830 Million C$	The cost of this proposal is 895 Million C$	The cost of this proposal is for twin girders 775 Million C$, while boxes is 910 Million C$	The cost of this proposal is 910 Million C$	The cost of this proposal is 910 Million C$

Table 1: Comparison of Alternatives (16)

Criteria	Concrete single box	Hybrid steel-concrete	Composite Superstructure bridge for twin girders and boxes	Composite Superstructure bridge with V shaped	Cable-stayed bridge
Operating and maintenance cost	Each model is facing different problems, but solutions to these problems could be close				
Construction time	The Construction time almost neutral for all models				
Environmental effects	Reduce number of piers compared to the existing bridge that will generate a better environment than existing bridge				
Aesthetics/Visual effect	Solution unexpected and is not suitable	Solution unexpected and is not suitable	Solution unexpected and is not suitable	Appropriate solution to implement	The best solution to implement
Architecturally	Model has no an attraction for tourism	Model has no an attraction for tourism	Model has no an attraction for tourism	Model has no an attraction for tourism	Model has an attraction for tourism
Advantages	Resistance to twisting, has ability to a long stretch, and strong for uses (18)	This model reduces the loads on the bridge and features a light deck.	This model reduces the loads on the bridge and features a light deck and the materials used has corrosion-resistant.(19)	This model reduces the loads on the bridge and features a light deck, and has a good visual effect	Featuring breathtaking view as well reduces loads on foundations by screwing "cables" as well features a light deck
Disadvantages	Too expensive, erosion the steel cables, moreover beyond repair (18)	Is not accurate because there are mixtures of concrete and steel	Too expensive, fire resistance is low, and the composite structural systems, as well as the lack competencies for maintenance. (19)	This model is complex in the implementation because depend on the composite pillar on shaped "V"	Is one of the bridges that considered complex for implementation " cables"

Table 2: Comparison of Alternatives (16)

Criteria	Traditional system	BIM system
Visualization	Difficulty vision the project before implementation as in fact especially the owner and contractor	Ease vision the project before implementation as in fact especially the owner and contractor by using 4D model schedule and simulation.
Design	The difficult of accurately design; Moreover, it takes time for completion.	Ease accurately design; Moreover, it takes short time for completion.
project cost	inaccuracies in the project cost as well as the cost may change in the implementation period.	Accuracies in the project cost as well as fixed project cost in the implementation period.
Project delivery	Variable	Steady
Team	Difficult communication among work team, as well as owner.	Easily communication among work team as well as owner from the beginning of design until project delivery.
Risk	Project management are non-common and inaccurate.	Project management are common "tied" and accurate.
Reports	Difficulty in obtaining project reports only after a few weeks.	Easily access to the project reports in a few minutes.
Education	Individual education by using traditional methods.	Collective education by using technology and modern methods.
Program cost	Inexpensive	Expensive

Table 3: Comparison among traditional and BIM system

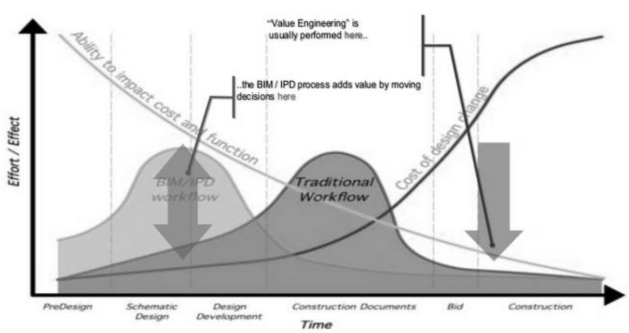


Figure 30: Comparison among traditional and BIM system (20)

	Construction constrains	Construction cost	Aestatic/ Visual effect	Advantages	Disadvantages	Architeturally	Overall score	Procentage
Concrete single box	3	3	2	2	1	2	11	**73.33%**
Hybrid steel-concrete	2	2	2	2	1	2	11	**73.33%**
Composite Supersteucture bridge for twin girders and boxes	3	3	2	2	2	2	14	**93.33%**
Composite Supersteucture bridge with V shaped	3	2	3	3	2	2	15	**100.00%**
Cable-stayed bridge	3	2	3	3	2	3	16	**106.67%**
	3	Favourable						
	2	less favourable					Chosen solution as it can	
	1	unfavourabla					become an icon form Montreal.	
	0	very unforable						

Table 4: Comparison of alternatives

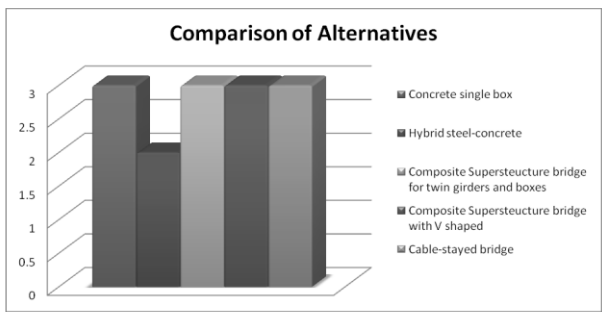


Figure 31: Comparison of Alternatives

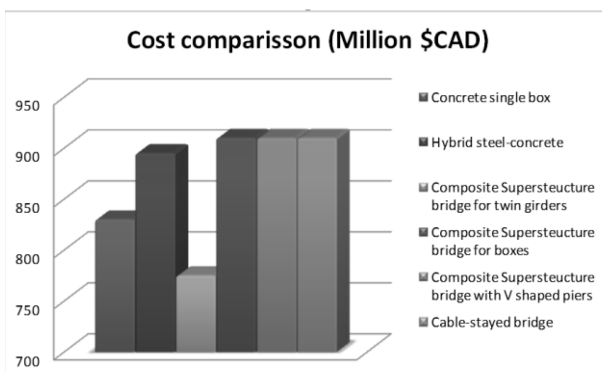


Figure 32: Cost Comparison (million $CAD)

6. CONCLUDING REMARKS AND FUTURE DIRECTION

After the analysis that was conducted for the proposed designs of the new Champlain Bridge, it can be concluded that the "Cable-stayed bridge" is the best proposal. This form of construction is characterized by high strength, and architecturally it will give an impression that is distinctive for Montreal city. This impression may also lead to increased tourism and raising the economic health of the region. Moreover the results suggest the "traditional design and project management" methods will create several problems before and after project implementation. These problems include: increased project cost, unreliable logistics, resource and material management, resilience, and changes in delivery time. Furthermore, these results suggest that BIM will most likely to have a positive impacts on the design, project management, costs reduction, profitability, better time management, ease in prediction of the future, information flow, as well as improved relationships between owners, contractors, and designer.

As a next step, we want to include a more detailed representation of the terrain and the structural design in the BIM system. Please note that currently the structural design of the project has not been finalized. A systematic indicators based comparison is required to quantify the improvements brought in by BIM compared to conventional approached. We will introduce dimensions beyond 5D in the developed BIM system. Moreover we intend to work closely with the industry to promote the use of BIM system in transportation infrastructure projects.

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