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APPLICATION OF BUILDING INFORMATION MODELLING IN A LARGE-SCALE  
TRANSPORTATION INFRASTRUCTURE PROJECT :  
A CASE STUDY OF NEW CHAMPLAIN BRIDGE

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Ce mémoire intitulé :

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TRANSPORTATION INFRASTRUCTURE PROJECT :  
A CASE STUDY OF NEW CHAMPLAIN BRIDGE

présenté par : SHETWI Rida

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## RÉSUMÉ

De nouveaux ponts sont largement considérés comme des grands projets d'investissement qui ont une signification à long terme pour le développement urbain et aussi de la société. Dans la région de Montréal, un tel projet est en cours, le pont de New Champlain. Conception traditionnelle, la planification et les méthodes de gestion des processus devraient être utilisées dans ce grand projet. Cette approche présente des majeures inconvénients/limitations: la mauvaise gestion des ressources rares dans l'économie actuelle; manque d'assurance de la conception durable; absence d'une analyse détaillée des effets environnementaux; un manque de changements automatiques de conception en réponse aux changements dynamiques; et enfin, des capacités limitées de visualiser et d'adapter la conception, les processus et les flux du projet. Les progrès récents dans la modélisation des données du bâtiment (BIM) apportent des réponses robustes, cohérentes et complètes à ces questions. BIM est un outil utilisé pour intégrer toutes les informations en un seul modèle, et il offre un moyen plus efficace de collaboration entre les intervenants par rapport à la méthode traditionnelle. BIM est également flexible dans le changement ou la modification du projet pendant la période de la conception ou de la mise en œuvre en un minimum de temps, et présente les phases du projet en temps réel. Dans cette thèse, nous développons un modèle basé BIM-pour le projet du pont de New Champlain.

Le modèle proposé est un modèle 5-dimensionnel (5D) qui comprend: d'abord, la visualisation tridimensionnelle (3D), avec une concentration sur la flexibilité du système dans la conception. Il calcule les quantités et les avantages du BIM pour le concepteur, propriétaire et l'entrepreneur pendant la période de la conception ou de la mise en œuvre. Le deuxième modèle est un calendrier et simulation 4-dimensionnels (4D) utilisés pour calculer les phases temporelles du projet et les avantages de la simulation, qui montrent les phases du projet avant la période de la mise en œuvre. Troisièmement, 5-dimensionnelle (5D) d'estimation du coût met l'accent sur la précision et la flexibilité de la vitesse de présentation et de coût du projet. Nous avons comparé le BIM et les systèmes traditionnels en utilisant des scénarios perturbateurs. Ces scénarios sont présentés comme exemples pour montrer comment le BIM et les systèmes traditionnels traitent les problèmes avant la mise en œuvre du projet, ainsi que durant la période de mise en œuvre. Nous avons analysé cinq scénarios de conception différents proposés par Infrastructure Canada, et nous avons choisi les deux meilleures propositions pour démontrer l'efficacité du BIM par rapport aux approches traditionnelles.

## ABSTRACT

New bridges are widely considered to be large investment projects that have long-term significance to urban development and society as a whole. In the Montreal area, such a project is underway-the New Champlain Bridge. Traditional design, scheduling, and process management methods are expected to be used in this great undertaking. Such as approach has major drawbacks/limitations: poor management of scarce resources in the current economy; lack of assurance of sustainable design; absence of a detailed analysis of the environmental effects; a lack of automatic design changes in response to changing dynamics; and lastly, 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. BIM is a tool used to integrate all information into one model, and it provides a more efficient way of collaboration between stakeholders when compared to the traditional method. BIM is also flexible in changing or modifying the project during the design or implementation period in a short time, and it presents the project phases in a real time scenario.

In this thesis, we develop a BIM-based model for the New Champlain Bridge project. The proposed model is a 5-Dimensional (5D) model that includes: First, 3-Dimensional (3D) visualization, with a focus on system flexibility in design. It calculates the quantities and the benefits of BIM for the designer, owner, and contractor during the design or implementation period. The second model is a 4-Dimensional (4D) schedule and simulation used to calculate the project time phases and the benefits of simulation, which show the project phases before the implementation period. Thirdly, 5-Dimensional (5D) cost estimation focuses on the accuracy and flexibility of the presenting speed and of project cost. We compared the BIM and traditional systems by using disruptive scenarios. These scenarios as examples to demonstrate how the BIM and traditional systems address the problems before project implementation, as well as during the implementation period. We analyzed five different design scenarios proposed by Infrastructure Canada, and we have chosen the best two proposals to demonstrate the efficiency of BIM in comparison to traditional approaches.

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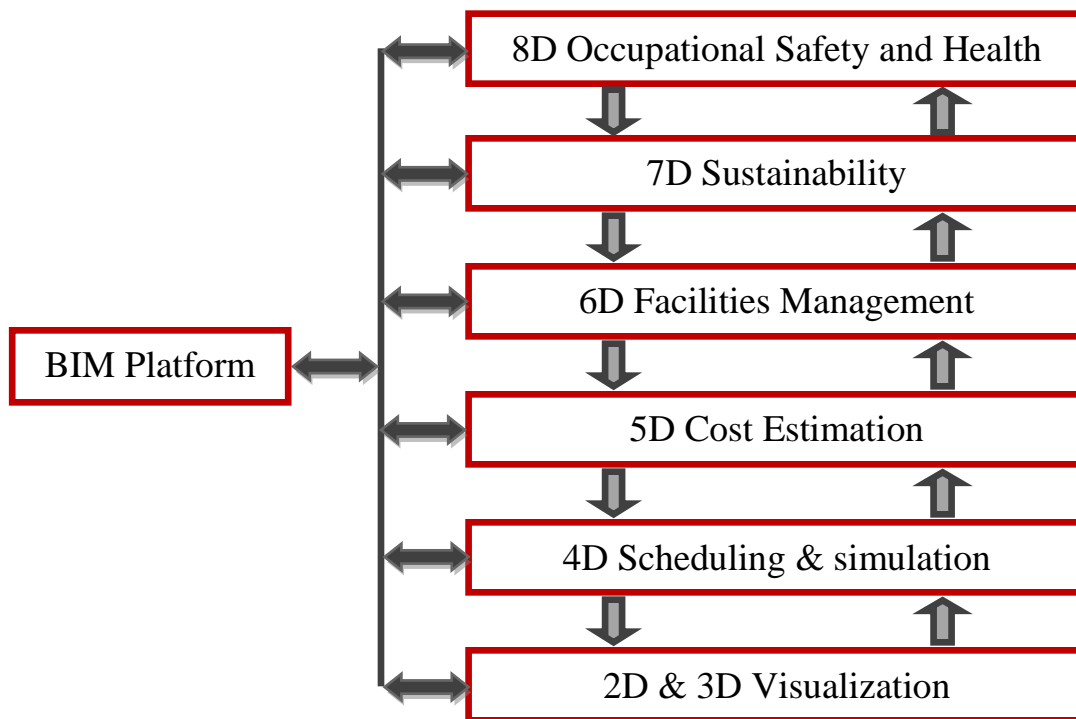
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## LIST OF ABBREVIATIONS

<b>BIM</b>	Building Information Modelling
<b>AEC</b>	Architecture, Engineering, and Construction
<b>RFP</b>	Request For Proposal
<b>CAD</b>	Computer Aided Design
<b>TIM</b>	Technical Information Manager
<b>IFC</b>	Industry Foundation Classes
<b>XML</b>	Extensible Markup Language
<b>ISO</b>	International Standards Organization
<b>IDM</b>	Information Delivery Manual
<b>BCF</b>	BIM Collaboration Format
<b>IFD</b>	International Framework for Dictionaries
<b>MVD</b>	Model View Definition
<b>2D</b>	Two Dimensions X and Y
<b>3D</b>	Three Dimensions X, Y and Z
<b>4D</b>	Schedule and Simulation
<b>5D</b>	Cost Estimation
<b>6D</b>	Facilities Management
<b>7D</b>	Sustainability
<b>8D</b>	Occupational Safety and Health

# CHAPTER 1 INTRODUCTION

Within the past few years, Building Information Modelling (BIM) has seen a significant increase in development in the fields of Architecture, Engineering, and Construction (AEC). Moreover, the use of BIM in the fields of civil, mechanical and electrical engineering is becoming more common. BIM is not restricted to only 3D views, but it also incorporates higher dimensions, such as 4D Scheduling, 5D Cost Estimation, 6D Facilities Management, 7D Sustainability, and 8D Occupational Safety and Health.



### Figure 1.1: The BIM platform

Figure 1.1 shows the platform of BIM system divided into eight levels beginning from 2D and extending all the way to the 8D model. The 2D and 3D visualization is the foundation for the BIM system and is also considered the starting point to eventually reach 4D-8D models. The goal of the 2D and 3D models is to determine the project details including material type. These details are then exported to the 4D model in order to determine the schedule of project stages and show the project stages in a real life simulation (including cost for each phase). Five-dimensional cost estimation also depends on importing the project details from the 2D and 3D models to determine the project cost according to markets prices of the state. The 6D model manages the movement of workers and machinery inside the project site in order to avoid the movement of workers and

machinery as well as any potential obstacles during the implementation period. Seven-dimensional sustainability also works by importing the 2D and 3D data to analyze the project energy. This model works to save the energy consumption that results from the exploitation of natural energy such as sun and air, etc. Eight-dimensional occupational safety and health model provides the workers safety inside the project site. It is important to note that in this platform, all models can import and exchange the data, as the BIM system integrates all information in one model. BIM is capable of maintaining the project implementation at the highest level of quality, giving architects and engineers the ability to predict the performance of projects in different scenarios before implementation (Strafaci, 2008). BIM can improve the design, changes in design, imagination or conception, design analysis, simulation, speed-up and facilitation of critical information availability, and can provide the highest project quality. We therefore predict that “BIM” will have a high level of applicability in large-scale engineering infrastructure projects, specifically in the transportation projects.

BIM is a process used for optimization of the lifecycle of infrastructure projects, starting from the design process, to implementation, to the end of the delivery process, and finally, to the sustainability of the project during its planned lifetime. There are, nonetheless, several challenges faced by "BIM". Some of these drawbacks include high cost of software/hardware, issues concerning responsibility designation, legal dimensions, etc. BIM has drastically reduced the magnitude of problems that are related to project implementation, both before and after. Examples include the cost and quality, whether public (government) or private (business or individual), which are considered of significant importance to the decision makers. For Example, the Shanghai Tower in China was built by using the BIM system and is considered to be the second-tallest tower in the world after Burj Khalifa in the UAE. This tower has a complex design with a height of 632 metres for a total floor area of 380,000  $m^2$ . Jianping Gu, general manager and director for Shanghai Tower Construction & Development Co. mentioned that *“We knew that if we tried to work in a traditional way, using traditional tools and delivery systems, it would be extremely difficult to carry out this project successfully.”* (Shanghai Tower Rising to new heights with BIM). As a system, BIM has been applied to several activities, including occupational health and safety, planning, constructability analysis, and operation of construction machinery to name a few. Studies conducted on the application of Building Information Modelling support a strong positive impact on their respective projects. Positive influences include improved

familiarity of the project problems before implementation, reduced project cost, speedy delivery, among others. However, it has been observed that BIM requires improvement in 3D visualization, project management, and facility management.

The aim of this research project is to demonstrate the utilization of BIM in a large-scale transportation infrastructure project. Specifically, we have presented the development of BIM processing for the New Champlain Bridge, which is to be built within next few years on the St. Lawrence River in Montreal. We have used the initial Request For Proposal (RFP) documents issued by Infrastructure Canada to develop the detailed model; however, several details that were used in this thesis were gathered from other sources, as Infrastructure Canada was unfortunately unable to support us with some confidential information. For this reason, we made several assumptions in this study, such as the final project proposal, the cost of materials for the project according to the Canadian market in 2008, and time for each of the project implementation phases until project delivery.

Moreover, the aim of this thesis is to demonstrate a complete application of a BIM system, because of its superior project management abilities from project design to project delivery phase. As well, the system has the ability to reduce problems that may arise during the project, either during the design period or during the project implementation period. Therefore, the "BIM" system developed in this thesis will provide integral support for the project, contributing positively to the project phases before implementation; to the reduction in problems that may arise during the project design period or during the project implementation period; and to the reduction of project cost estimates and delivery of the project in reliable time compared to the traditional design.

So, we address the benefits and drawbacks of using BIM in the feasibility study, in project implementation, and in project delivery. We also compared the performance of BIM with the use of conventional project management approaches. The remainder of the research paper is organized as follows: first we present a detailed review of the current literature related to BIM. We then discuss the methodology adopted in this research. We continue to explain the implementation of BIM for the case study of the New Champlain Bridge. We then analyse and discuss the results of the implementation. Finally, we discuss the conclusions and future directions of this work.



## CHAPTER 2 LITERATURE REVIEW

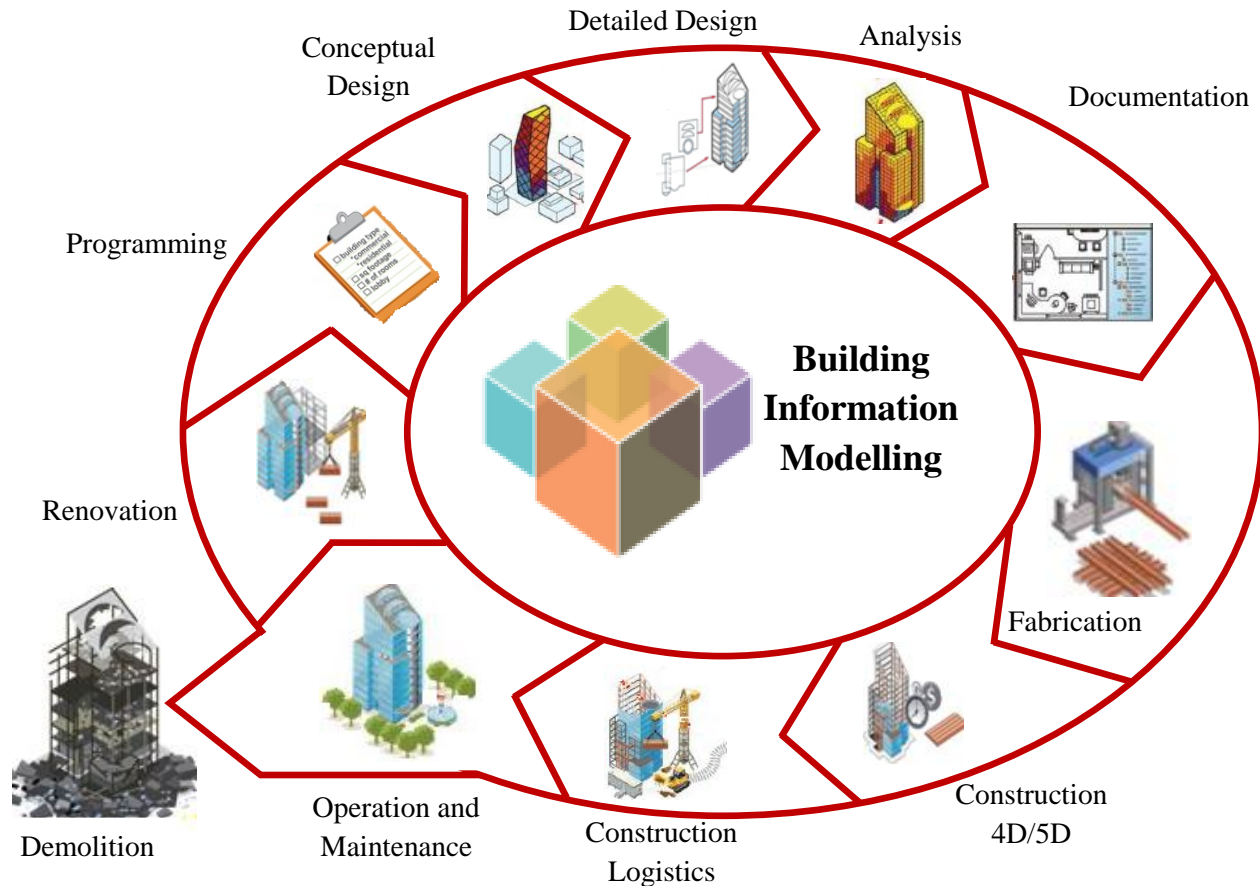
The first evidence of engineering and architectural drawing was, as we know, called "Freehand" drawing. This was the traditional method, practiced since the emergence of drawing, and carried on until the 1960s. Due to the advent of the computer age, there has since been a significant change in engineering and architectural drawing. The year 1960 is considered to be the beginning of a new technology called Computer Aided Design (CAD) ([Tornincasa & Di Monaco, 2010](#)). This technology led to drastic global changes in terms of speed and accuracy of engineering and architectural drawing. CAD started off as being a 2-Dimension (2D) visualization technology. In 1970, CAD advanced from 2D to 3D modelling, and several commercial softwares such as AutoCAD, ArchiCAD, SketchUp, etc. became available ([Hergunsel, 2011](#)). These 3D CAD technologies continued to develop until the 1990s. More significant developments in CAD technology came in the 1990s when higher dimensions, including 2D, 3D, and 4D models, were introduced and consistent modelling of buildings were presented in the form of Building Information System (BIM). Several commercial softwares were developed, including AllPlan, Revit, AutoCAD, ArchiCAD, SketchUp, etc. The aim of BIM is to improve the lifecycle of projects from the beginning of the design process to the delivery of the project. Furthermore, it was envisioned to aid the owners and decision-makers to closely monitor all the project stages (e.g. construction planning, scheduling, cost estimation, etc.), before and during the implementation ([Hergunsel, 2011](#)).

CPA Ontario ([A Brief History of BIM, 2012](#)) defined Building Information Modelling as a process of integrating all information related to the infrastructure construction project into one consistent model. BIM not only supports architects in designing the form and aesthetics of the infrastructure, but it is also a model to support engineers to design and analyze its structure and components. Furthermore, it is a tool that can be used to optimize the project's life cycle and processes, to easily predict the performance of a project in the design period before implementation. Most importantly, it may be used to solve the problems and project risks before implementation with high levels of accuracy. The detailed information generated by BIM can describe the project cost, the required resources, the availability schedule, the time of the project delivery, among other factors. BIM also supports simulation and visualization, which can describe the scheduling process by animating the implementation stages of the project from the beginning of the design phase to the delivery of the infrastructure ([Strafaci, 2008](#)).

Another explanation of the BIM stated in (Schianchi, 2014) is:

*"Building Information Modelling (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".*

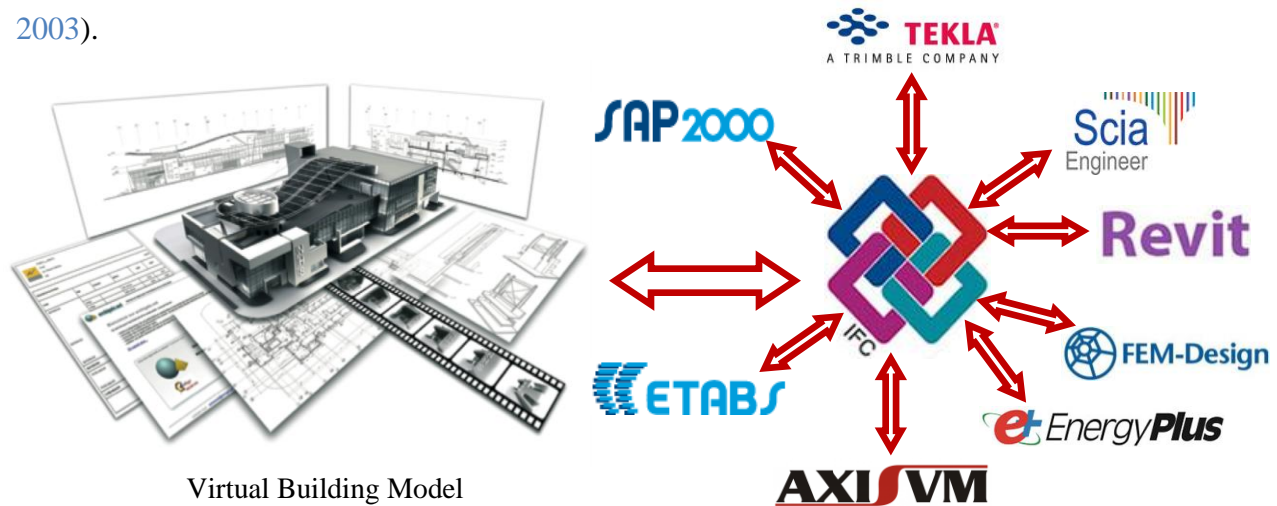
Figure 2.1, describes the various project stages that can be modelled and simulated in the BIM.



**Figure 2.1: The BIM lifecycle for project stages (#BIM: Bringing a "sea change to the industry's workflow")**

For the consistent exchange of information, a standardized model called Industry Foundation Classes (IFC) was introduced by International Standards Organization "ISO" 10303 (Shen, Orr, Choi, Kim, & Kim, 2014). This system was established in 1994 by the Autodesk and has been used as an industrial standard since 1996 (Laaks & Kiviniemi, 2012). IFC is a process of transferring software data among engineers, owners, designers, contractors, etc. as well as exchanging information or data between nations (Froese et al., 1999). Figure 2.2 shows the widely available support of the IFC model in the industry. Without IFC, the sharing of

information within BIM and across various BIMs would be very difficult. Therefore, this system is supported by more than 150 softwares, including: Allplan, Neviswork, and Revit, etc (Froese, 2003).



**Figure 2.2: The IFC support** (Working with Consultants)

We conducted a comparison between the traditional design and design by using the BIM system, as follows:

## 2.1 Communication

### 2.1.1 Organizational Coordination

According to our study, organizational coordination is an important factor when managing the project both before and after implementation, as it shows effective work of the project at hand (Hemphill, 2009). Moreover, coordination is a process used to organize the communication between activities (Hemphill, 2009). It includes several important strategic standards, such as integration of activities, responsibilities, and command and control structures. Coordination, thus, allows for the usage of resources in the most efficient way (KULLVÉN & NYBERG).

Furthermore, coordination is a process of improving the relationship among all project collaborators such as the owner, the designer, the contractor, and the workers. Therefore, it will allow for a high quality of coordination and collaboration within the project management. This feature may have a significant impact in reducing the problems of error proportion in the projects (Hemphill, 2009).

Efficient collaboration usually faces several problems and difficulties when trying to achieve goals that have a high quality. These goals may be common or un-common between project

teams, dependent on unexpected events. In this case, one must understand and respect the views of each team, which may be different on several points (KULLVÉN & NYBERG). Therefore, the respect among project teams is vital to provide a successful project implementation (KULLVÉN & NYBERG). Moreover, the focus on managing interpersonal relationships within the project team, as well as developing trust for one another both have a positive impact for providing successful work in the project (Hemphill, 2009).

### 2.1.2 Information Sharing

Information sharing is important to manage the project and has a large influence over its level of success or failure. Information sharing is the exchange of data between employers (owner, contractor, and designers), where the information is in the form of drawings or reports (Hatala & Lutta, 2009). A few years ago, information sharing was done via traditional methods (mail), but with the technological advancements over the past few decades, there were several models discovered for sending information, such as the telephone, the computer (internet). etc. Information sharing can presently be divided into three categories: **push, pull, and interactive information sharing** (KULLVÉN & NYBERG).

Push is considered to be a part of the information sharing system, where this system functions by sending information or data using email through phone or Internet. This is a fast system for sending information, however, it does not ensure that the information has reached the desired person or company (Volda, Edwards, Newman, Grinter, & Ducheneaut, 2006).

Pull is also considered to be part of information sharing, but this system has the capacity to pull and retrieve information when needed. This information may be on the web produced by media solutions (Volda, Edwards, Newman, Grinter, & Ducheneaut, 2006).

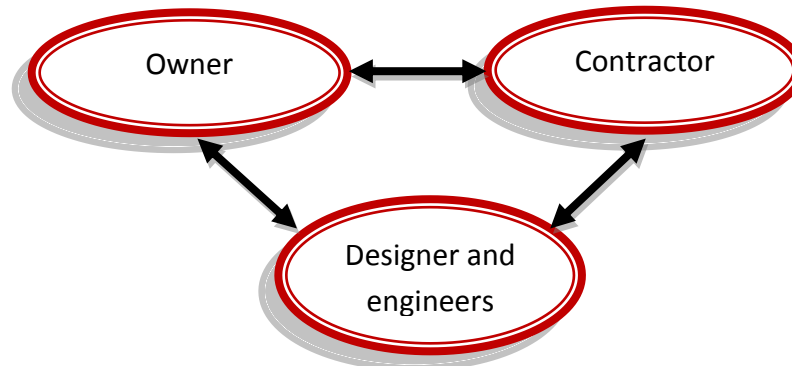
Interactive information sharing is performed by communication via email, phone, and Internet. Information exchange and communication among project teams increases the speed and accuracy of the work development (KULLVÉN & NYBERG).

### 2.1.3 Actors

Actors are a foundation for project implementation, from the start of the project until project delivery. As shown in Figure 2.3, the actors are divided into several categories- owners,

contractors, and designer. The project starts with the owner- the person or party who pays for the facility, is for choosing the type of materials used, and determines the project cost. Moreover, the owner will own the project after the construction is completed (KULLVÉN & NYBERG).

However, when the project is started, an architect or engineers are responsible for the facility design (KULLVÉN & NYBERG).



**Figure 2.3: Key of project implementation**

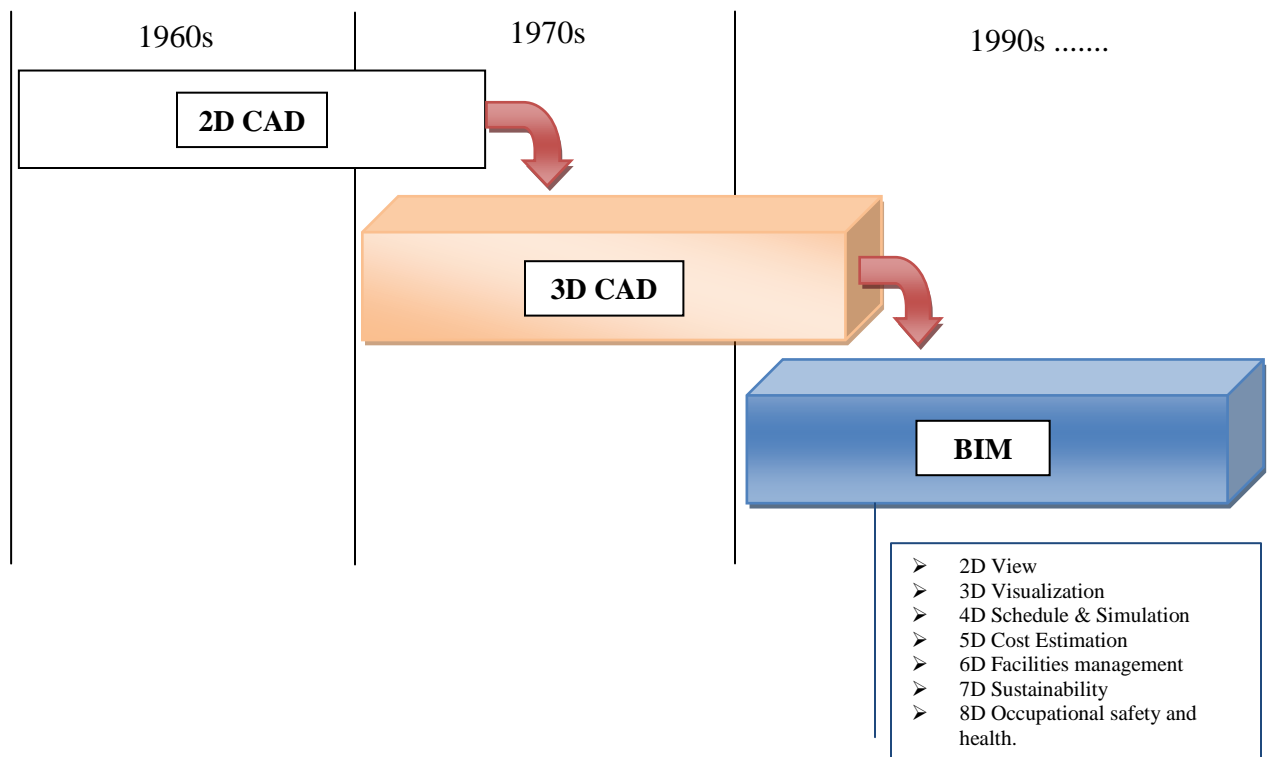
As well, the owner, who is given feedback from the engineer, can appoint different roles to the contractor, who acts as the owner's agent. The role of the contractors is to form agreements with the owner regarding the details of construction. There are usually several contractors responsible for different parts of the project. The contractor is responsible for controlling and implementing the different project stages, but is not responsible for choosing the type of materials or addressing the problems relating to project design. The Figure below exhibits the parties responsible for the aforementioned roles in a project (KULLVÉN & NYBERG).

## 2.2 Traditional Design Method

### 2.2.1 Design

Design is an important process for projects development. Design has three generations: **the first generation** was without Computer known free hand drawing. Using this method, not only was it difficult to develop an accurate project, but it took a long time to complete the project design and it was difficult to predict the project phases. The function of design is determined using the technical specifications and drawings. These drawings helped the parties figure out the project planning. **The second generation** was after new technology was discovered (Computer and CAD). This period was the transition to the new system CAD, where the function of CAD is to draw the 2D project. Although by using this model, it took little time to draw out a project, it still

had its disadvantages (KULLVÉN & NYBERG). For example, it took a long time to complete the drawing stage, it was difficult to provide a project without problems, and there was difficulty predicting the project phases. As shown in Figure 2.4, a 2D model has been developed from a 2D to a 3D model, where the 3D model helps the owner and contractor predict the project phases, however, inaccurately because it is non-integrated (KULLVÉN & NYBERG). However, a few years ago, a new system known as Building Information Modelling (BIM) was discovered. This system develops 3D models and life cycle projects to resolve past problems. This system is considered to be the third generation.



**Figure 2.4: Phases of design development**

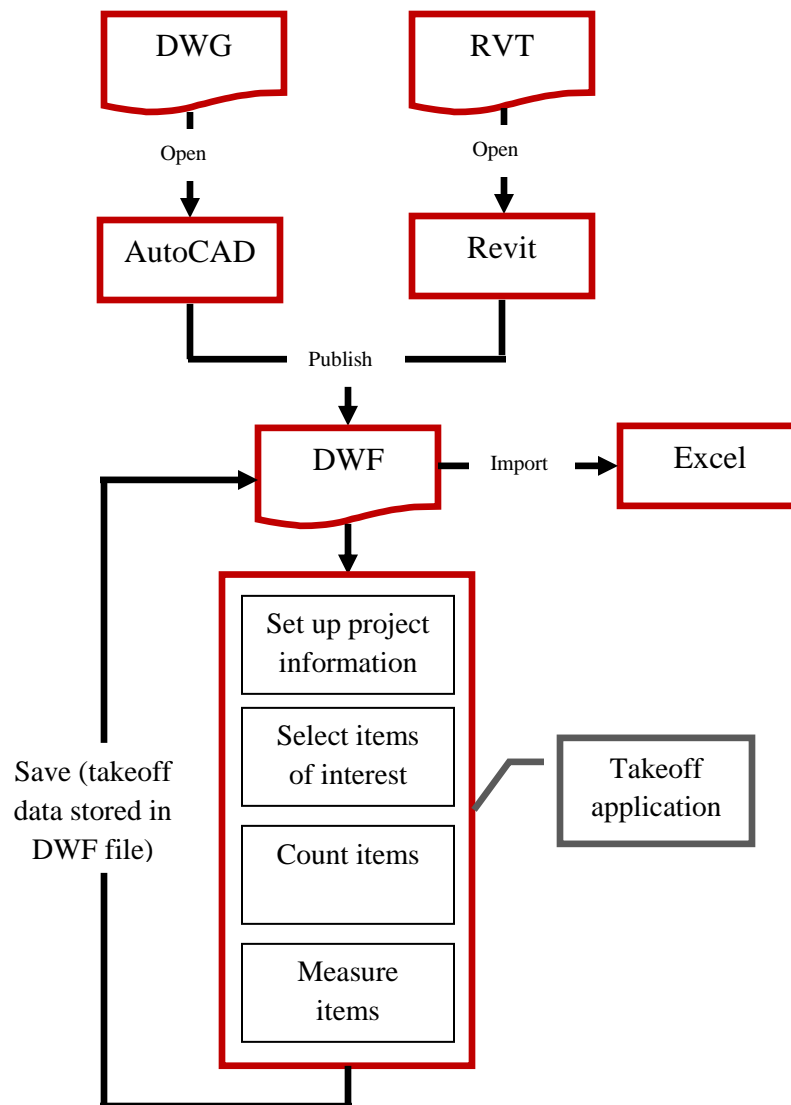
### 2.2.2 Quantity Take-off

Quantity take-off is a process used to determine the project cost. It works to determine the detailed measurements for the project, such as labour, materials, time, and cost to figure out the project budget and produce a construction. Quantity take-off is dependent on several categories (Quantity Takeoff for Cost Estimation - BLIS-Project):

- Location by area
- Structural system

- Columns in terms of count and size
- Span in terms of area
- Seaway system
- Cables in terms of size

A few years ago, quantity take-off was measured manually to determine the construction cost of a project from 2D drawings, but this process was inaccurate and took a long time. This method is still used today, and there are currently several softwares that support this process to extract cost estimation of a project. These softwares take little time to determine and provide the potential construction cost of a project. They are also very accurate (Boon & Prigg, 2012). Shown in the Figure 2.5 is one of the softwares that support quantity take-off under Autodesk platform.



**Figure 2.5: Extract quantity take-off by using DWF system (Roginski, 2011)**



### 2.2.3 Cost Estimation

Cost estimation is an important part of project implementation. A few years ago, the cost estimation was dependent on manual calculation and good knowledge of production cost. This knowledge came through experience from previous projects (KULLVÉN & NYBERG). There are two categories of cost: direct costs and indirect costs, where direct costs refer to construction materials and indirect costs refer to insurance, electricity, and waste disposal (KULLVÉN & NYBERG). However, this "traditional method" was inaccurate and took a long time. It also has significant errors in the implementation period. If the errors in the design and cost calculation period are not spotted, large sums of money must be spent in order to change the cost in a project implementation period.

But, the transitional phase occurred in 1980s (KULLVÉN & NYBERG) when the computer was introduced to support cost estimating by using Excel Spreadsheets (MTI Systems, Inc. Celebrates 30 Years of Innovative Cost Estimating for Manufacturing). This technology contributed to solving several problems, such as easily determining the errors in a project as well quickly determining project cost estimation. Results found by using this method are much more accurate than those found using the traditional method. As technology continued to develop, several software systems have emerged to support cost estimation. Among them, the BIM system is considered to be the best system to support the lifecycle of a project (Zhao & Wang, 2014).

### 2.2.4 Scheduling

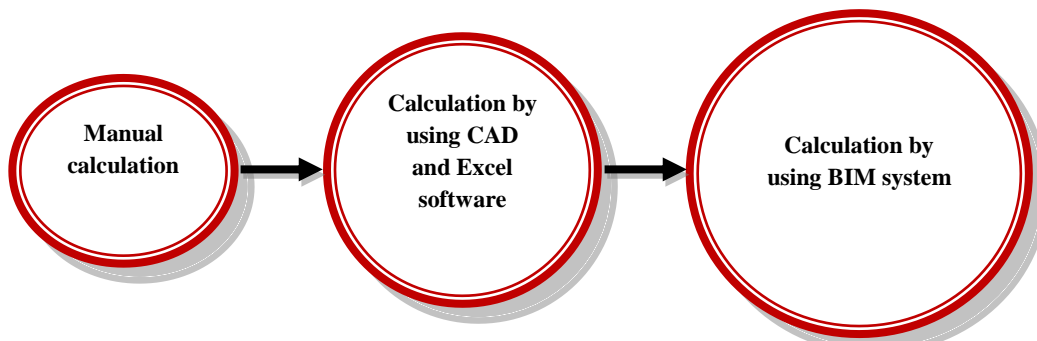
All projects require a realistic and accurate schedule due to infringement risk at the implementation and delivery period. The scheduling is usually dependent on the personal experience of the professional. As shown in Figure 2.6, the history of schedule systems is divided into three generation, as follows.

**The first generation** the traditional method was used before technology emerged. It is dependent on manual calculation, 2D drawing, and the experience from previous projects. This method is inaccurate, takes a long time, and is an unorganized way to determine the phases of project delivery. Moreover, it has significant errors in the implementation period, resulting in wasted money spent on changing the phases of project delivery later on in development (Weldu & Knapp, 2012).



**The second generation** occurred after new technology was discovered (Computer and CAD). This period was a transitional period into a new system used to calculate scheduling and time of project delivery by using CAD software and Excel. Excel works by manually inputting data from 2D drawing, whereas the aim of CAD software is to develop, communicate and construct schedules and better visualization in order to avoid problems and risks during the project implementation phase. However, this generation was not integrated to provide all the guarantees of delivering phases of a project at the fixed date ([Weldu & Knapp, 2012](#)).

**The third generation** was introduced after development of CAD technology from 2D dimensional to 3D dimensional view. In the last few years, this technology has been developed into the BIM system, which integrates all information into one model. The aim of this system is to provide a highly integrated system. However, BIM is not only used for scheduling but it is also used during project simulation, where studies have proven that this system is successful and has a high accuracy in the design phase and in the planning and scheduling of a project ([Büchmann-Slorup & Andersson, 2010](#)).



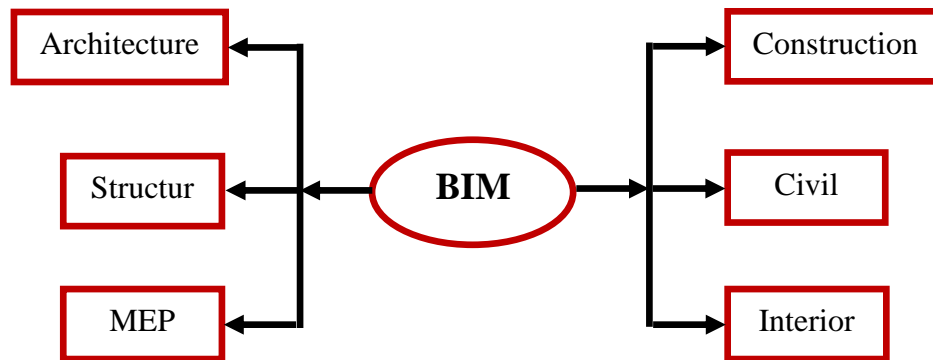
**Figure 2.6: Automated generation phase of 4D model (schedule and simulation)**

## **2.3 Design by Using a New System (BIM)**

### **2.3.1 BIM System**

Building information modelling (BIM) is a process used to integrate all information into one model. It is considered to be an intelligent system used to manage the project life cycle from design to project delivery. It also allows cooperation within all parties, as well with all software, such as Allplan, Revit, Tekla, and CAD, etc ([Sullivan, 2007](#)).

Moreover, BIM is flexible to change and project design before and after implementation, where it supports several fields, such as architecture and civil engineering, etc including as shown in the Figure 2.7.



**Figure 2.7: Structure of BIM support**

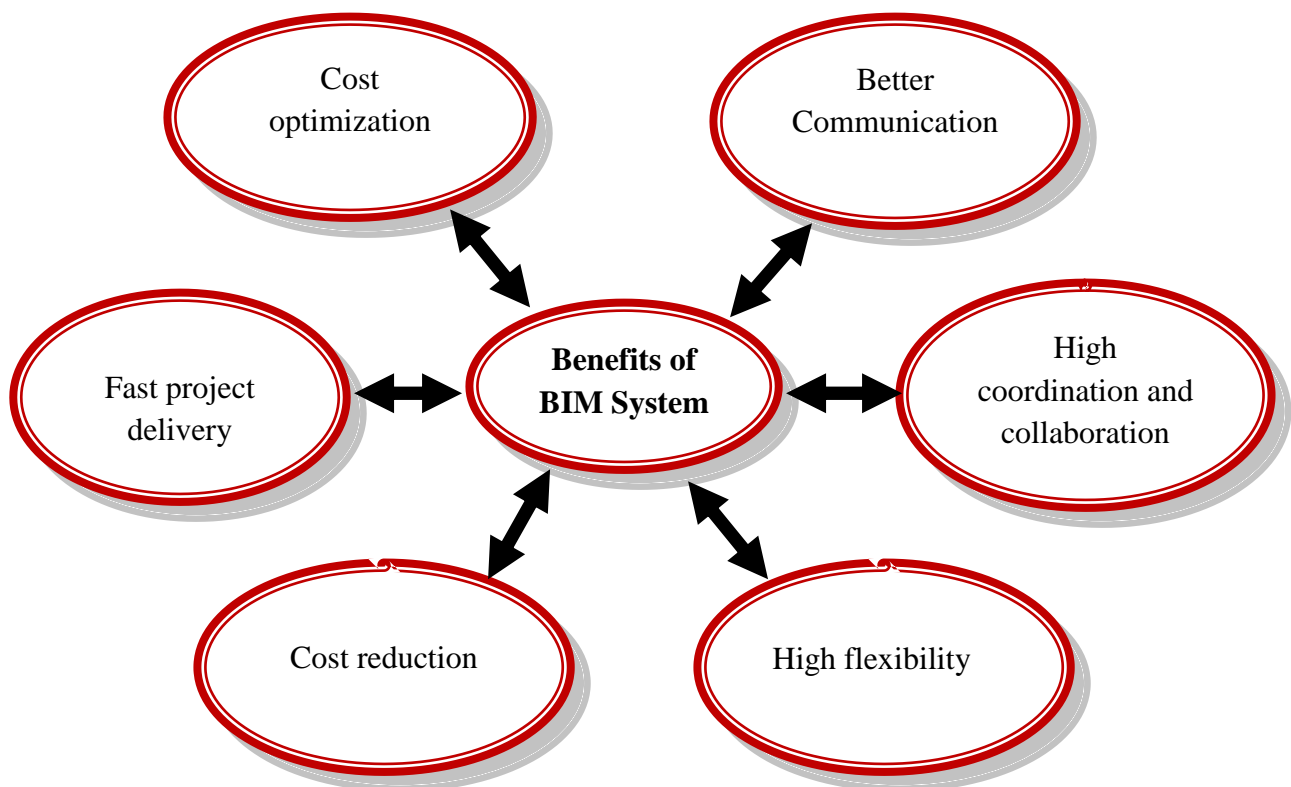
BIM usually leads to changes regarding new needs and modern development in society, as it is a contemporary model. This system is highly accurate and allows one to make easy decisions regarding project design and implementation (whether from the designer, owner or contractor). It is also easy to spot all design problems before construction, and it is easy to know the costs and timing. Lastly, BIM provides high project quality and lower costs compared to traditional design and allows for the flexibility of choosing one's materials. The drawbacks of this system include its complexity, causing it to be difficult to use for people with less computer experience. As well, BIM requires a computer with a high specification. The end results of the BIM system provide high designs and analyses for all project parts (Sullivan, 2007).

### 2.3.2 Benefits of BIM

According to our studies, BIM has been focused on the construction of homes, but in last a few years, BIM has also been developed for the implementation of mega-projects, including high buildings, bridges, roads, etc. Several countries have used BIM as a successful and accurate system. Furthermore, BIM has significant benefits for the life cycle of a project before and after implementation, described as follows (Azhar, 2011):

- A. Easy cooperation among the parties of the project, which produces several advantages, such as reduction in project cost and project delivery simultaneously;
- B. Easy to figure out all problems and risks before construction implementation;

- C. Flexibility to change or modification of the design without any constraints;
- D. The cost automatically changes when you modify any element or part of the project. For example, an increase or decrease in the number of columns will cause the cost of the project to change;
- E. Easy to choose the type of materials depending on the quality (high or low);
- F. The owner and contractor can find out all project stages before implementation (by 3D view and simulation);
- G. BIM has a significant ability for cost management, time management, communication, coordination, and quality management;
- H. Easily to access all project information as a report (PDF or Microsoft Word). For example, columns in terms of count and size, etc;
- I. Easy to make critical decisions regarding the facility, whether from the designer, owner or contractor.
- J. BIM has the ability to make design iterations regarding the project, costs, etc.



**Figure 2.8: Benefits of BIM System**

### 2.3.3 3D Visualization Based on BIM

As shown in Figure 2.9, a 3D visualization is considered to be the foundation of BIM system. These types of models give a complete view for the project's "real vision", where this vision helps the parties (owners, contractors, designers, and engineers) figure out all project details, as well as make fateful decision for the project. Such decisions include design change, color choice, materials, etc ([Azhar, 2011](#)). Additionally, 3D modelling provides high accuracy for the project as well as reduces the project costs and time. It also allows for figuring out all project problems before implementation. The 3D BIM model has the ability to exchange information with any software by using, for example, Industry Foundation Classes (IFC) ([Azhar, 2011](#)). This specific model works by inputting all project information through 2D drawing. At the same time, one chooses or changes the type of materials needed in that section. For example, when designing columns, one could choose the type of material (steel or concrete) as well as the size (length and width), so when all of this information is inputted, the model will automatically change from 2D to 3D. Moreover, this model is resilient and accommodates changes in design, materials, etc ([Azhar, 2011](#)). The materials are supported electronically through an online file-sharing service from the same software company.



**Figure 2.9: Visualization of a bridge**

### 2.3.4 Quantity Take-off Based on BIM

Quantity take-off is an accurate process and is the starting point of both the scheduling and cost estimation of the project. A few years ago, quantity take-off was calculated manually and as previously mentioned, was inaccurate and took a long time. Most of these projects faced problems at the implementation period due to this of lack of accuracy (KULLVÉN & NYBERG). After new technology was discovered, there was a reduction in these problems as people started using CAD. CAD software evolved from 2D to 3D views, but several problems remained because the model was not integrated. When the 3D model evolved in the BIM system, the results were much more accurate. Using this system, one can determine the type of material used according to the country's code. By using the BIM system, the quantity take-off inputs the specific data into the model and includes the cost estimates and scheduling. This process may be difficult, because it requires experience in order to determine the time. Therefore, it may be inaccurate, however, the advantages of this method include being able to determine the specific price of the cost estimation. In addition, another positive aspect of this method includes determining the type of material used according to your country's code (KULLVÉN & NYBERG).

There are several softwares that allow BIM systems to perform quantity take-off, such as the Revit and Allplan software etc. As shown in Figure 2.10, the software is based on a 3D model and works by a geometry analysis algorithm used to study or check the 3D model. Moreover, it can automatically extract information from the 3D model, which is included in the cost estimates (Ma, Wei, & Zhang, 2013). The BIM system has several advantages. For example, the BIM data updates automatically by companies that support the BIM system. This system gives clear and accurate information, allowing one to easily follow the schedules and cost estimation data, and allows for good communication between team and owner.

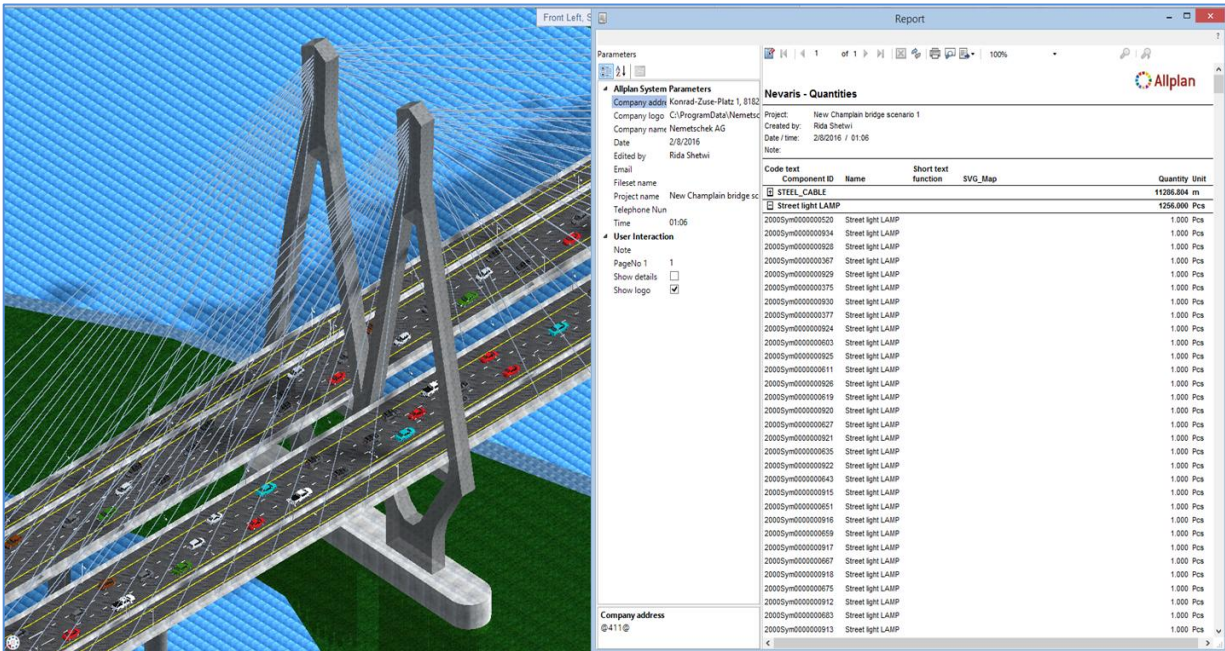


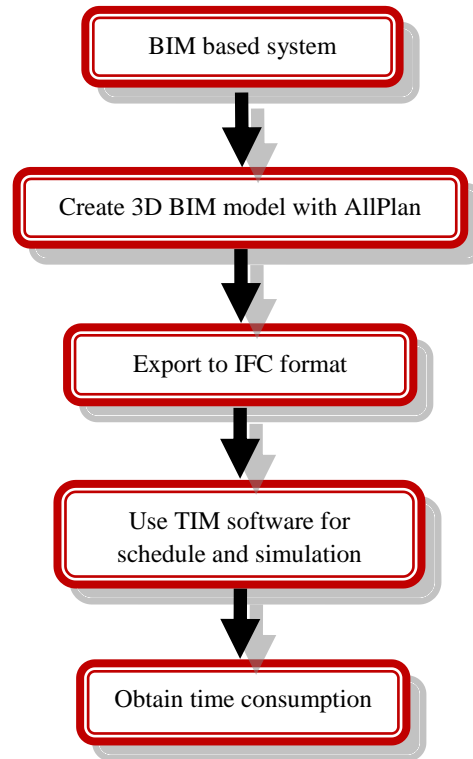
Figure 2.10: Quantity take-off by using Allplan software

### 2.3.5 Scheduling Based on BIM

Scheduling is a process based on a 3D model, where the function of this model is to determine information regarding project implementation phases in terms of space and time (Hu, Zhang, & Deng, 2008). The traditional method is dependent on manual calculations, where these calculations are usually inaccurate. There are different ways in which the project can be implemented at the site. These problems lead to issues during the project delivery period, which include inaccuracy of the time of project delivery, an increase in project cost, among others. These complications have a significant impact on both project parties (owners and contractors) (KULLVÉN & NYBERG).

For the aforementioned reasons, it is important to rather focus on 4D BIM system "Scheduling" to address these problems. This type of system has achieved significant success in determining the accuracy of the project delivery period and has reduced cost in several large-scale projects around the world, with locations in Japan, Dubai, USA, etc. The 4D model of "scheduling and simulation" obtains a clear and complete vision of the project from the start all the way to project delivery (Brito & Ferreira, 2015). As shown in Figure 2.11, this model works by exporting the 3D BIM model by Industry Foundation Classes (IFC) to softwares that support this 4D model, such as TIM, and Naviswork, etc.



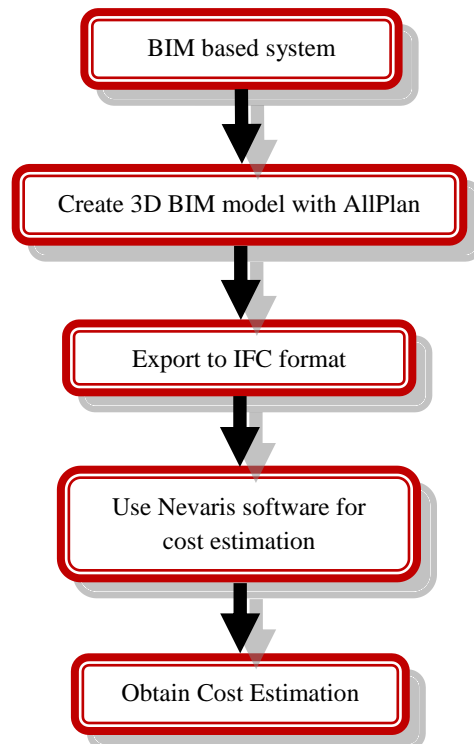


**Figure 2.11: Process sequence of schedule and simulation by using BIM**

This software works to accurately link all project activities in the plan and to properly order these activities or entities in sequential order. It seeks to perform all project phases as best as possible (Brito & Ferreira, 2015). Moreover, the 4D BIM "scheduling and simulation" model provides the visualization of the entire project, helping the parties to easily predict the project's performance, its cost management, its supply management, and its risk management. The simulation provides all its information (time and costs for all project phases) via video (Brito & Ferreira, 2015). The features of this system have high accuracy, making it easy to perform critical decisions, whether from the designer, owner or contractor. Not only is it easy to know the phases of project delivery, but this system has resilience and accommodates changes in timing of the project stages (Brito & Ferreira, 2015). These features lead to reduction in cost and timing of project delivery compared to traditional method. The disadvantage of this system, however, is that several softwares can be complicated to use for people with little computer knowledge. As well, software licences are very expensive, for example, the cost of TIM software, which is around \$4000. However, the end result of this system provides a detailed vision of the project phases.

### 2.3.6 Cost Estimating Based on BIM

Cost estimation is an important process in the life cycle of a project's implementation. As mentioned earlier, there are several methods used to calculate cost estimation, but it is important to focus on the BIM system. Why is this system successful and accurate? Cost estimation of the BIM system is referred to as the "fifth dimension" and is based on the 3D and 4D models. 5D functions by exporting the 3D BIM project quantity take-off by using the Industry Foundation Classes (IFC) to cost estimate software. Quantity take-off determines the material type, number, and size of object quantities (Forgues, Iordanova, Valdivesio, & Staub-French, 2012).



**Figure 2.12: Process sequence of cost estimation by using BIM**

This system is particularly resilient and accommodates changes in material, size, number, and price. One can therefore change data manually or by directly using the software data. The type and price of materials are supported by the same software company. For example, Nevaris software has a specific office known as Nevaris office, which supports and updates data. Some disadvantages include difficulties in use of the software for people with less computer experience. Other drawbacks include the fact that software licences are very expensive and that this software does not support all markets. For example, Nevaris software does not support Canadian Markets, while it does support German Markets.



After inputting the 3D model in the cost estimation software, it automatically generates calculations. Furthermore, when the designer or owner wishes to change or modify the model or cost database, the cost estimates will automatically change. Moreover, some features of this system include its high level of accurately, its ease in making fateful decision for cost estimates, and its way of figuring out all problems for cost estimates before construction implementation. As well, the future costs are known, and figuring out the cost developments in the market can be done with ease ([KULLVÉN & NYBERG](#)).

### **2.3.7 Industry Foundation Classes (IFC)**

IFC is a process of providing and exchanging information among project parties. This process is considered to be an international open standard and is developed by the organization Building Smart. Building Smart is working to overcome problems that IFC faces through the exchange of information between software. Examples of these software programs include Revit, Allplan, Naviswork, Tekla, and CAD ([Jensen, 2015](#)). Information cannot be exchanged between these softwares without the help of IFC. Moreover, IFC is a process of providing and exchanging information around the world and between manufacturers and providers who implement and manage the project life cycle. One can take advantage of this information for maintenance of the project after implementation. For example, if the model requires modification, the company sends the model information to the manufacturer, who then directly sends it to the company ([Jensen, 2015](#)).

Moreover, there are several standards used to share information between softwares. Examples of these process standards include International Framework for Dictionaries (IFD), BIM Collaboration Format (BCF), Model View Definition (MVD), and Information Delivery Manual (IDM), ([Jensen, 2015](#)).

## 2.4 Summary of Comparison

Comparison among traditional design and design by using BIM


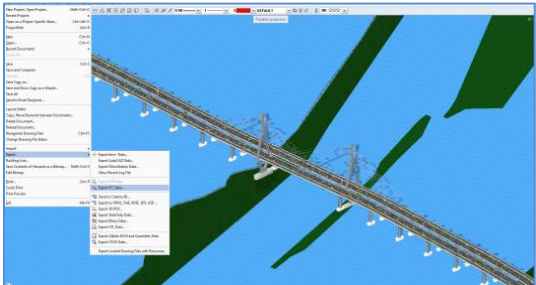
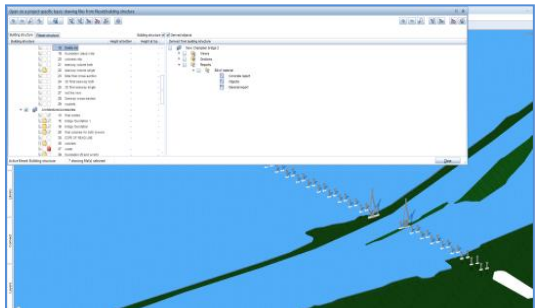
**Table 2.1: Summary of comparison (traditional method vs. BIM system)**

Project factor	Traditional Design	Design by using BIM
<b>Team</b>	Fragmented and difficult communication among work team, as well as owner	Easy communication among work team as well as owner from the beginning of design until project delivery
<b>Communication</b>	Cooperation difficulty among the parties of the project due to cooperation through securities and paper-based 2D dimensions	Ease of cooperation among the parties of the project whether in the same state or different state by using technology, such as the Internet by sending IFC file "complete project", and project reports as PDF file or Microsoft Word
<b>Risk</b>	Project management is not common and is inaccurate, as the management is run by the individual	Project management is commonly "tied" and accurate. The management is run by the linked team
<b>Design</b>	The difficulty of accuracy in design. It takes time for completion.	Accurate design. Moreover, it takes a short period of time for completion with high quality performance
<b>Visualization</b>	Difficulties in project vision before implementation among the owner and contractor	Good project vision before implementation among the owner and contractor by using 3D Visualization, 4D Schedule and Simulation, 5D Cost Estimation
<b>Materials</b>	This system has resilience and accommodates changes in materials or size and numbers of quantities, and prices are calculated manually according to your data	This system has a significant resilience and accommodates changes of materials or size and numbers of quantities, and prices; therefore one can change data manually according to the data or by directly using the software data. The type and price of materials are supported from the same software company

**Table 2.1: Summary of comparison (traditional method vs. BIM system) (Continued)**

<b>Project factor</b>		<b>Traditional Design</b>	<b>Design by using BIM</b>
<b>Project change</b>		Difficulty in changing the design and it takes long time to change or modify with a lower quality	Flexibility to change or modify the design without any constraints and it takes short time with a high quality
<b>Project Cost</b>		The project costs are inaccurate and the cost may change during the implementation period	The project costs are accurate, as well as the project cost is fixed at the implementation period
<b>Project delivery</b>		Variable	Steady
<b>Reports</b>		Difficulty to obtain the project reports only after a few weeks, and the reports as a 2D dimension and as a document	Easy to access or obtain the project reports in a few minutes, and the reports are presented as 2D and 3D with electronic documentation, such as PDF
<b>Software</b>	Cost	Inexpensive	Expensive
	Use	This system is easy to use for people with less experience	BIM is complicated to use for people with less computer experience
<b>Education</b>		Individual education by using traditional methods	Collective education by using technology and modern methods

Table 2.2: Summary of comparison (traditional method vs. BIM system)

Project factor	Traditional Design	Design by using BIM
<b>Team</b>	Fragmented and difficult communication among work team, as well as owner	<p>Easy communication among work team, as well as owner</p>  <p>(Autodesk Amps Up BIM with Expanded Cloud-based Collaboration Services)</p>
<b>Communication</b>	Difficulty of cooperation among the parties of the project, because of the cooperation through securities, and these paper based on 2D	<p>Flexibility of cooperation between project parties due to the cooperation through electronic files such as IFC file</p> 
<b>Design</b>	Difficulty of maintaining accuracy in design. Moreover it takes time for completion	<p>Accuracy in design. Moreover it takes short time for completion</p> 

**Table 2.2: Summary of comparison (traditional method vs. BIM system) (Continued)**


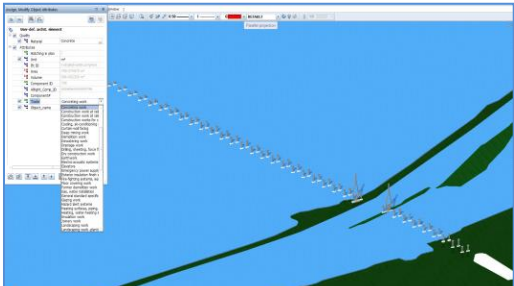
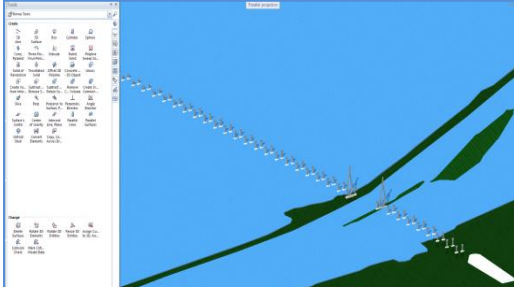
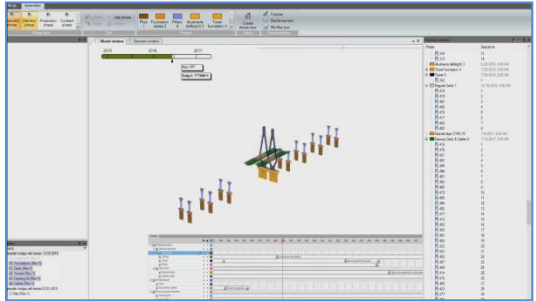
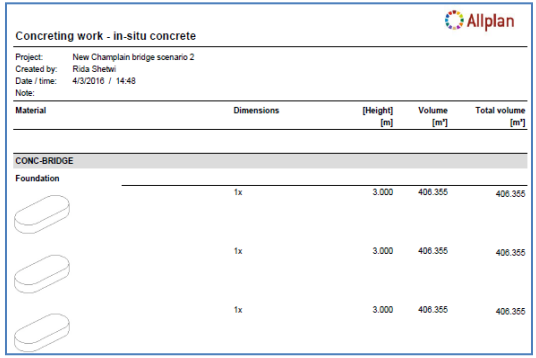
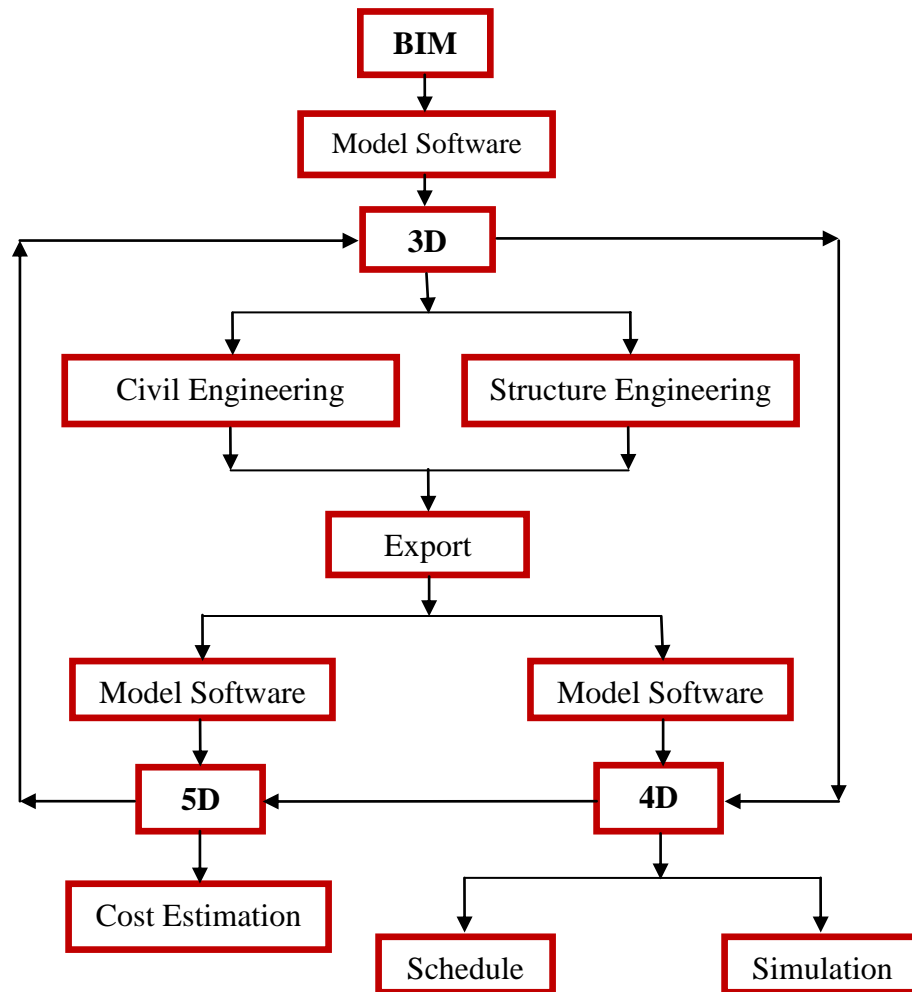
Project factor	Traditional Design	Design by using BIM
<b>Visualization</b>	Difficulties in project vision before implementation, specifically for the owner and contractor	<p>Ability to present the project as in real life setting before implementation, specifically for the owner and contractor</p> 
<b>Materials</b>	This system has resilience and accommodates changes in materials or size. Prices are recorded only manually according to the data	<p>Flexibility in choosing and changing materials. The materials are modified according to the country's code that supports BIM system</p> 
<b>Project change</b>	It is difficult and requires a lot of time to change or modify the design with a lower quality	<p>It is flexible and requires a short period of time to change or modify the design with a higher quality</p> 

Table 2.2: Summary of comparison (traditional method vs. BIM system) (Continued)

Project factor	Traditional Design	Design by using BIM
<b>Project Cost</b>	The project costs are inaccurate and the cost may change during the implementation period	<p>The project costs are an accurate and fixed during the implementation period.</p> <p>The project delivery is at a fixed time according to the regulation</p> 
<b>Project delivery</b>	Variable	
<b>Reports</b>	Difficult to obtain the project reports within the first few weeks, and the reports are presented as 2-dimensional document	<p>Easy to obtain the project reports within the first few hours, and the reports are presented as a PDF or Spreadsheet files</p> 

## CHAPTER 3 METHODOLOGY

The goal of this research project 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, we consider the New Champlain Bridge project, which is considered an important link to the trade route between Canada and USA. 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 modelling, TIM software 4D schedule and simulation, and Nevaris for 5D cost estimation. Figure 3.1 shows the steps that were followed in order to develop the BIM system.



**Figure 3.1: Flowchart of BIM**

We describe the process of development for each dimension as follows.

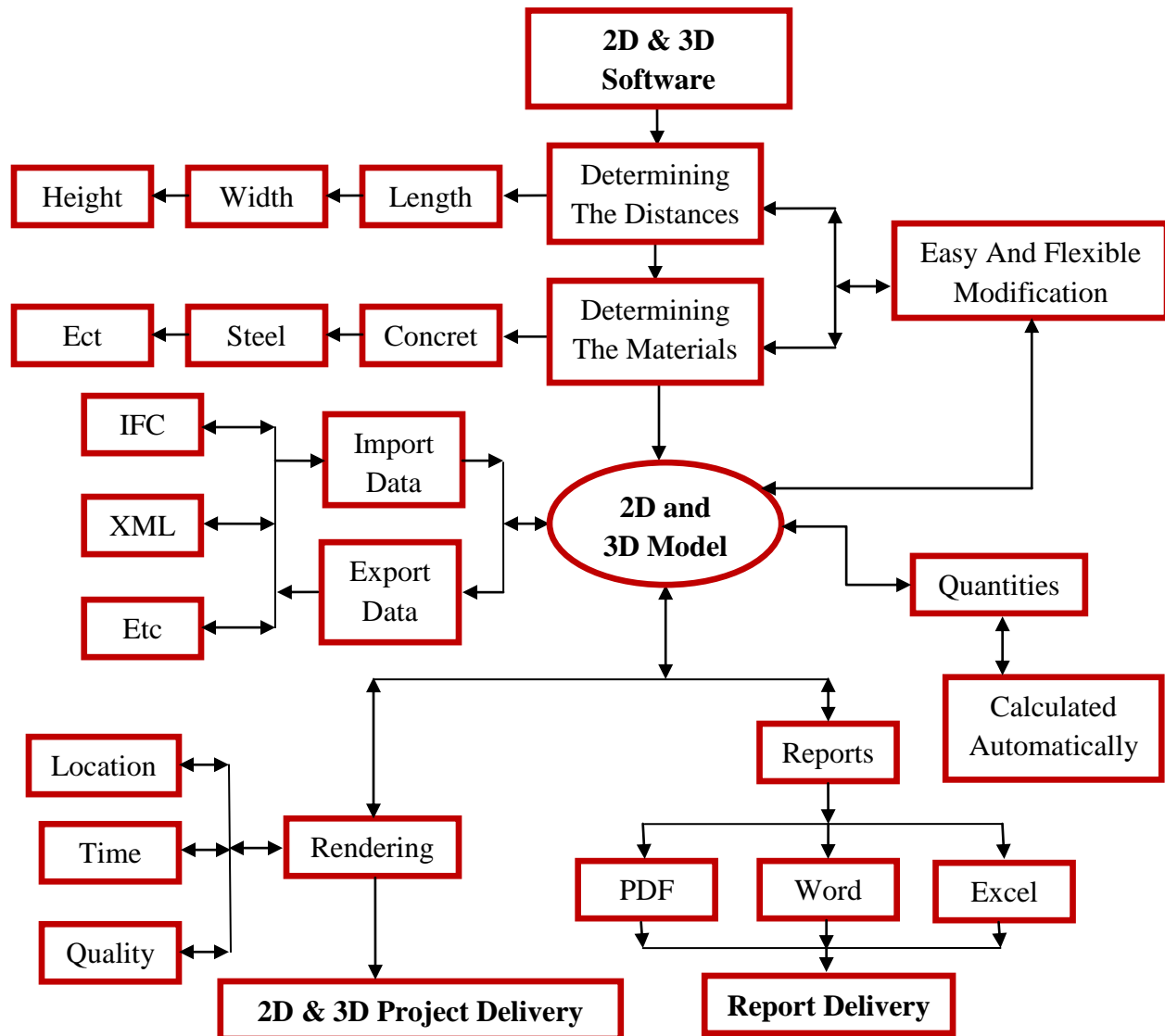
### **3.1 3D Modelling (Visualization)**

3D visualization provides the basis for higher levels of BIM e.g. 4D schedule and simulation, and 5D cost estimation. 3D modelling can help owners, engineers, and contractors make quick decisions relating to the 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 modelling is actively used in designing roads, bridges, and buildings for quick changes and for the evaluating the effect of the architectural design. For example, if one wants to change the dimension or remove a column, this can rapidly be done using the 2D or 3D model, allowing the software to automatically update the entire project. Furthermore, during the design phase, 3D modelling allows one to choose the types of material, depending on the type of units and the country's codes. Detailed reports on the specific project and highly rendered models for visualization are available in various formats including an interactive PDF file format. Furthermore, using a 3D model allows for the exportation of the project data to the IFC data standard.

We will determine the terrain points for a New Champlain Bridge project by using the SketchUp software because Infrastructure Canada does not provide the terrain points in the reports. SketchUp software is known to support the BIM system, which takes the terrain points directly from Google Earth. These data (terrain points) will then be exported to Allplan software.

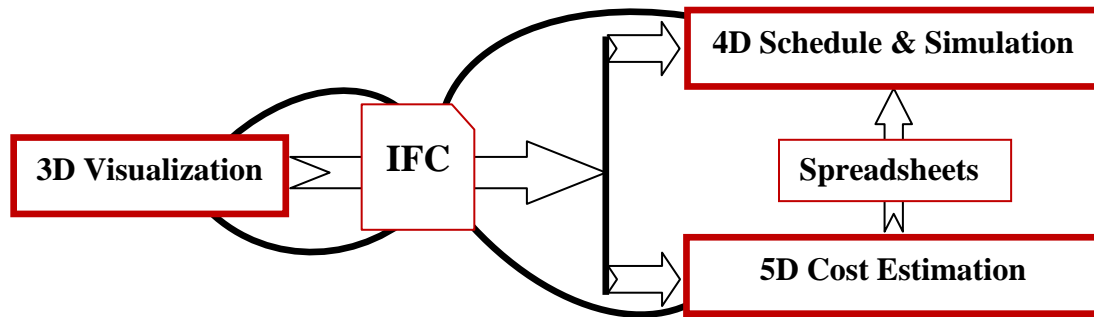
In this thesis we will use Allplan software to design a New Champlain Bridge. This software is considered to be one of the softwares that support a 3D BIM system. As shown in Figure 3.2, this software has the flexibility to input all project data, where these data are collected according to Infrastructure Canada reports. These data include length, width and height for each category. Infrastructure Canada provided a New Champlain Bridge project data as shown in Chapter four Figures 4.3 to 4.16. In this case, we will re-design the project in the Allplan software by using available data in the reports as 2D drawings. These drawings include all information regarding distance such as length, width, height as well angles. The type of materials is estimated according to the German code due to the Canadian code's failure to support BIM systems.





**Figure 3.2: Flowchart of software (2D & 3D)**

The quantity takeoff in the BIM system is calculated automatically during the design period after the type of materials for each category is determined. All project data including the type of materials and quantity for each category is presented as a PDF or Spreadsheet file. Then, as shown in Figure 3.3, we will export all project data as a IFC file to softwares that support a 4D schedule and simulation and 5D cost estimation. This is done because the IFC file platform exchanges all project information between all softwares that support BIM systems.



**Figure 3.3: Flowchart of exported 3D data by IFC file to a software that supports BIM**

### **3.2 4D Modelling (Schedule & Simulation)**

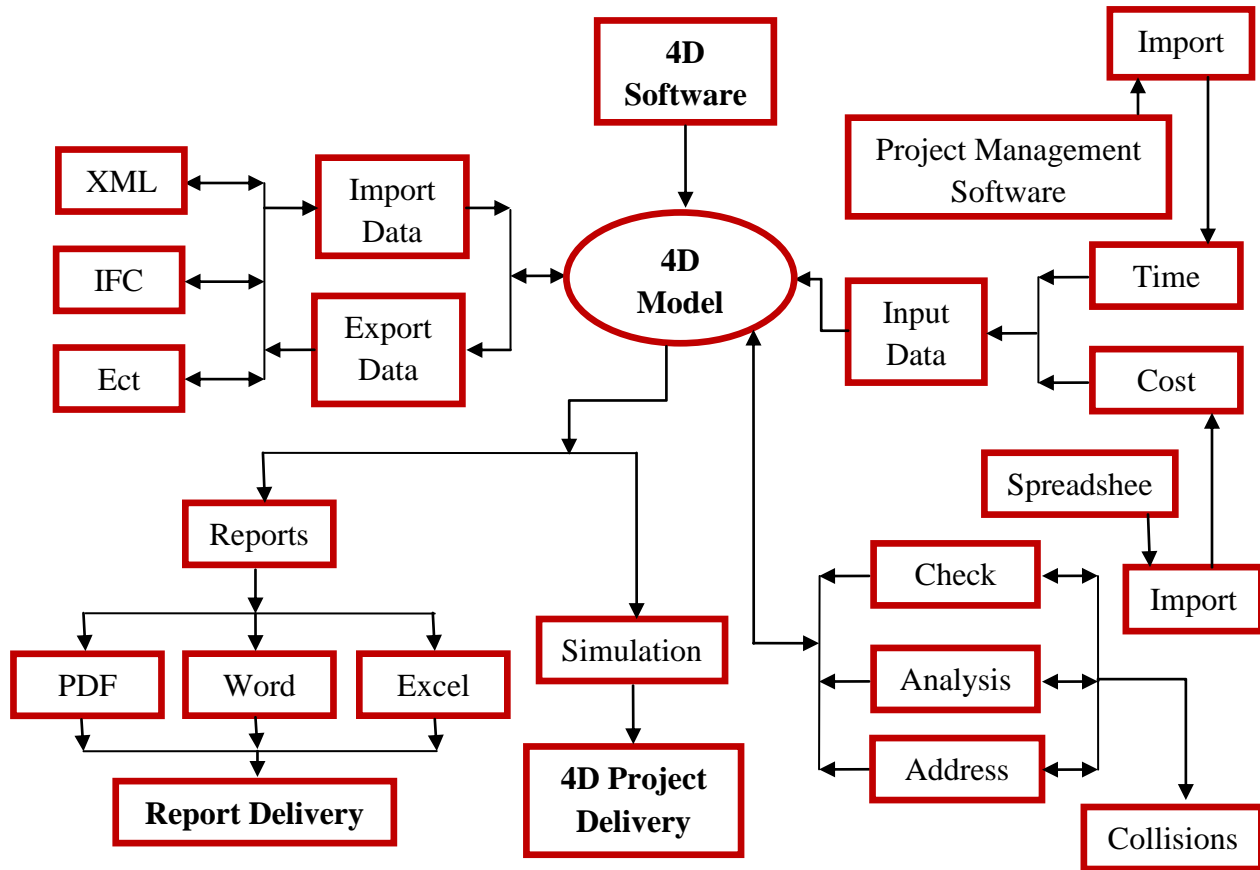
4D modelling is part of the implementation of the project design phase that is based on the 3D model. The scheduling process takes place after the completion of the 3D model of the project design. Once 3D modelling is completed, it is then exported using IFC standards to develop the 4D modelling in the schedule module of BIM software. After exporting the data to the 4D model, which includes drawings and quantities, the designer who is experienced in calculating the project scheduling, performs the calculation of the project schedule which includes all project phases such as deck, piles and columns etc. This calculation is then entered into the 4D model, for example, it is entered as the time period from the beginning to the end of the column implementation. The 4D model can directly show the results of detailed estimates, which may include the time and cost of all project phases in a real life scenario. Four-dimensional modelling helps the owner and contractor figure out detailed estimates at any time throughout the phases of project implementation.

Moreover, 4D supports simulation by creating an animation from the software like, Naviswork, and TIM, for example. Using these interactive animations, one can observe the project implementation from the very beginning to the end of 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 fixing the clashes without lose time and while avoiding cost overflows.

In this step, we will use the Naviswork software, which supports a 4D schedule and simulation and is considered to be one of the softwares that support the BIM system based on 3D modelling. As shown in Figure 3.4, we will first calculate all project times manually, according to the 3D

visualization data. All project data will then be imported from Allplan software as a IFC file. These data include all project phases.

As a second step, we will input all project times using a Project Management Software. This file will include the project schedule which we will calculate manually, and then the project cost will be imported as a spreadsheet file according to the 5D cost estimation software. All project stages will be presented as an animation file. This simulation will enable the visualization of all project phases in a real life scenario, and it will present all project data as a PDF or Spreadsheet file.



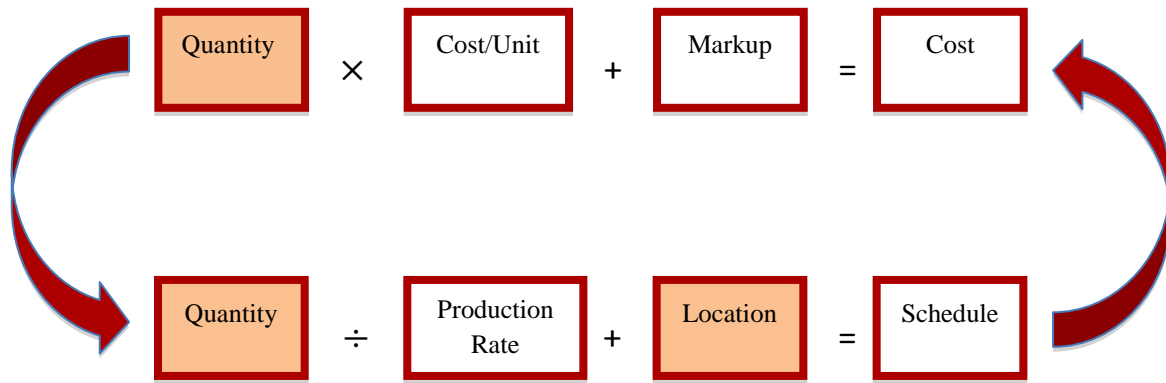
**Figure 3.4: Flowchart of the 4D software system**

### 3.3 5D Modelling (Cost Estimation)

5D modelling is a process that comes after scheduling and is based on 3D modelling. This process is achieved by exporting the quantity take-off, which is the starting point of both scheduling and cost estimation of the project. The quantity take-off first requires determining the type of materials that will be used for project implementation during the design. The designer is the one who selects the type of materials during the 2D and 3D design according to the project

regulations. For example, the type of materials that are used in the project may be steel or concrete. If the material used is concrete, one must determine the concrete types- reinforced or prestressed. After the completion of the design and determination of the type of project materials, the designer exports all project data by using the IFC model, to softwares such as TIM, Nevaris or other softwares that support the 5D model. The costs are determined based on the unit prices according to the state market.

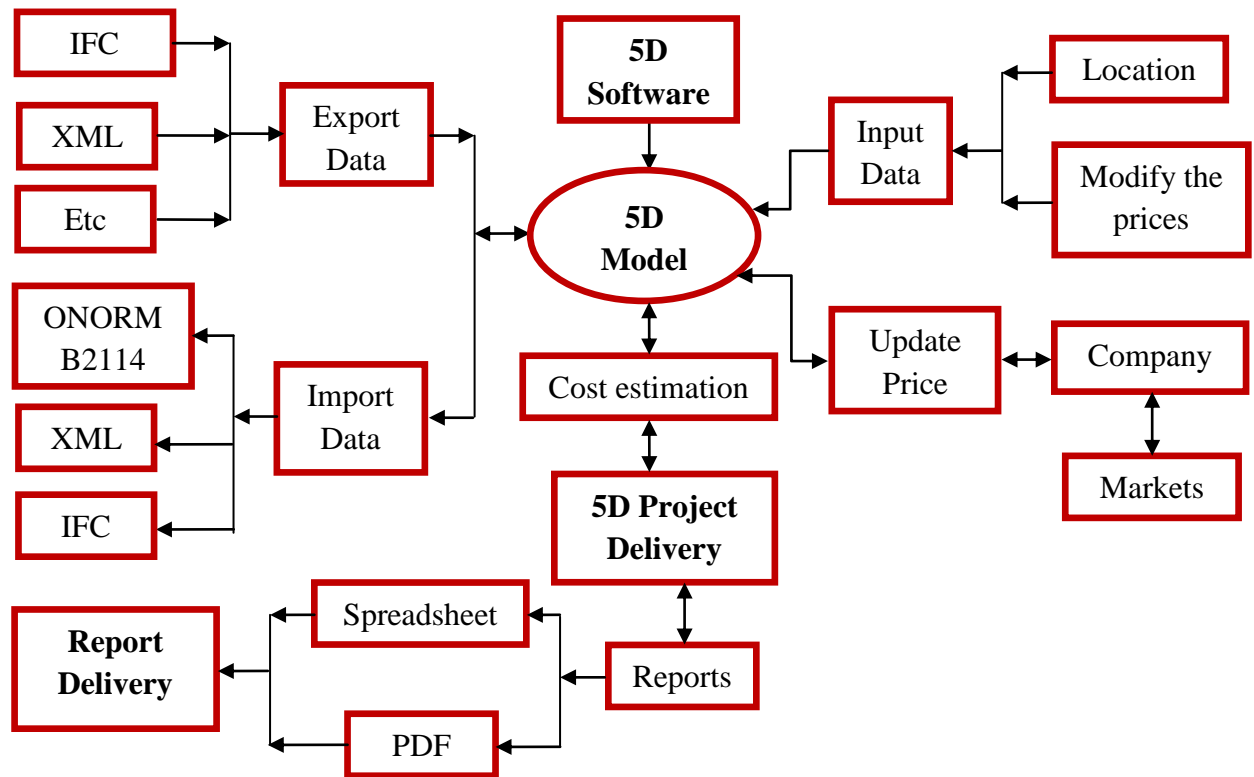
Finally, after process completion, a detailed report on all tasks such as steel cable, deck concrete etc., quantity, unit quantity, and unit price as well as total project costs can be analysed. The cost calculation process in the 5D model is shown in Figure 3.5. Please note that for this study, we have restricted the scope to 5D only and the higher dimensions of BIM are not considered.



**Figure 3.5: 5D cost estimation** (5D BIM | Model-Based Estimating | Construction Estimating Software)

As shown in Figure 3.6, we will use the Nevaris software in this step to calculate project cost. This software is considered to be one of the softwares that support the 5D BIM system. This step is based on quantity takeoff, which is calculated using 3D modelling, where the price is estimated according to the German prices because Canadian markets does not support the BIM system. First, we will import all project data from the 3D modelling as a IFC file, then we will determine the unit price CAN \$.

The software will then automatically calculate the project cost for each category according to the type of materials, which will be determined in the 3D modelling system. We will present all project costs as a PDF or Spreadsheet file.



**Figure 3.6: Flowchart for a typical 5D software system**

## CHAPTER 4 CASE STUDY

We chose construction of the New Champlain Bridge over the St. Lawrence River in Montreal as our case study. This is one of the biggest transportation infrastructure projects in recent history of Canada ([Archived - Government of Canada Marks the Official Start of Construction on the New Champlain Bridge](#)).

### 4.1 Existing Champlain Bridge

The Champlain Bridge is considered to be an important transportation link to the east-west passage of Canada between Canada and USA. The original Champlain Bridge was constructed in 1962, but in recent years, experts have discovered cracks in the bridge, making it vulnerable to collapse. The Canadian government thus decided to build a New Champlain Bridge that will have a life span of 125 years. It will have more lanes and will also take into account the problems present in the infrastructure of the Old Champlain Bridge.

As shown in Figure 4.1, the existing Champlain Bridge consists of three lanes in each direction. Moreover, in both directions, one of these lines is reserved for buses during peak times, and the traffic volume of this bridge is 145,000 vehicles per day ([Ferguson, 2011](#)). The length of this bridge is 3.5 km and the long span is 365m. The construction cost of this bridge was CAN \$35 million in 1962 ([Carlin & Mirza, 1996](#)). The Champlain Bridge is currently experiencing higher congestion compared to other bridges connecting the island of Montreal to rest of the province. It is also considered to be one of the most congested bridges in North America ([Ferguson, 2011](#)).

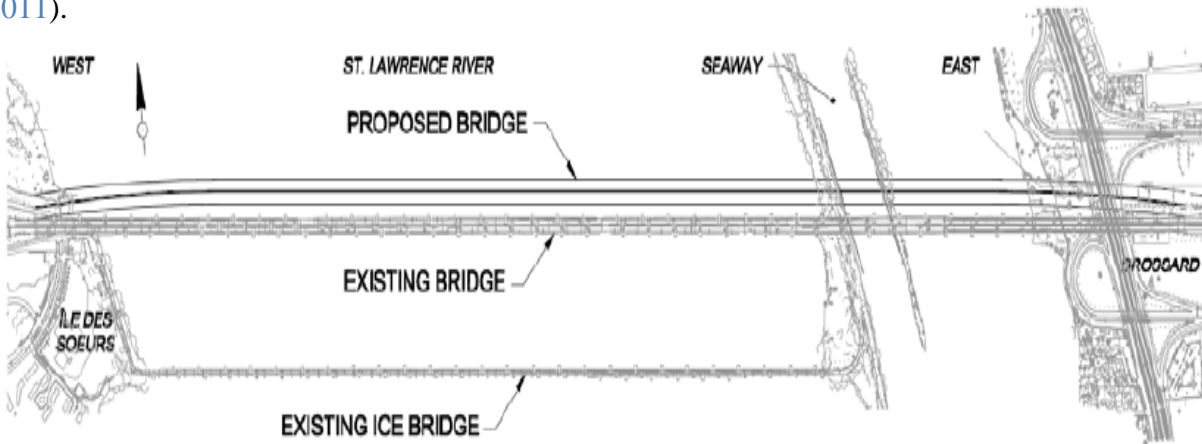


**Figure 4.1: View for existing Champlain Bridge** ([Ministry of Transports Quebec, 2011](#))

## 4.2 New Champlain Bridge

A New Champlain Bridge is considered to be 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 the United States. Additionally, it is important for the commute of the local population.

According to the studies on a New Champlain Bridge by Infrastructure Canada, it is expected that traditional methods would be used for the design and project management of the bridge. These methods may generate problems in the design, scheduling, and process management. This approach may contribute to a lack of assurance for a long-life design, to high levels of accuracy, to consistent information availability, and to sustainability (Ministry of Transports Quebec, 2011).



**Figure 4.2: Plan location of a New Champlain Bridge** (Ministry of Transports Quebec, 2011)

Figure 4.2 shows a New Champlain Bridge located 10 meters North of the existing Champlain Bridge, with a length of 3.5 km and divided into three parts, as follows (Ministry of Transports Quebec, 2011):

- A. The length of the first section is about 2,300 meters, located on the St. Lawrence River crossing, between Nun's Island and the seaway;
- B. The length of the second part is about 400 meters, located on the seaway crossing;
- C. The length of the third part is about 800 meters, located on the Eastern access, spanning between the Seaway and Highway 132.

The speed of the existing bridge is 60 km/h, while the proposed speed for a new Champlain Bridge is expected to be 100 km/h and is still under study (Ministry of Transports Quebec, 2011). Therefore, from our point of view, the advantages of an existing speed of 60 km/h is that the

accidents rate is lower, because in this case the driver can control the vehicle during the driving ([Transport, 2006](#)). While the disadvantages include spending a longer time crossing the bridge, which leads the users feeling uncomfortable, especially the users who use the bridge every day as a link between Montréal and other cities such as Brossard. The advantages of the proposed speed of 100 km/h include providing comfort to the users while crossing the bridge, and access to the workplace or housing in reduced time. But the disadvantages are that this may lead to an increase in the rate of accidents ([Transport, 2006](#)); otherwise, the existing and proposed speed depend on the behaviour of users, because the behaviour of users has a significant impact on bridges or any road.

Moreover, Infrastructure Canada states that the life expectancy of the New Champlain Bridge will be over 125 years, with construction costs ranging between \$775 and \$910 million. Five types of bridges were proposed as follows ([Ministry of Transports Quebec, 2011](#)):

- A. A pre-stressed concrete box girder bridge;
- B. A hybrid steel-concrete bridge;
- C. A composite bridge;
- D. A composite bridge with V-shaped piers on both shores of the seaway;
- E. A composite cable-stayed bridge.

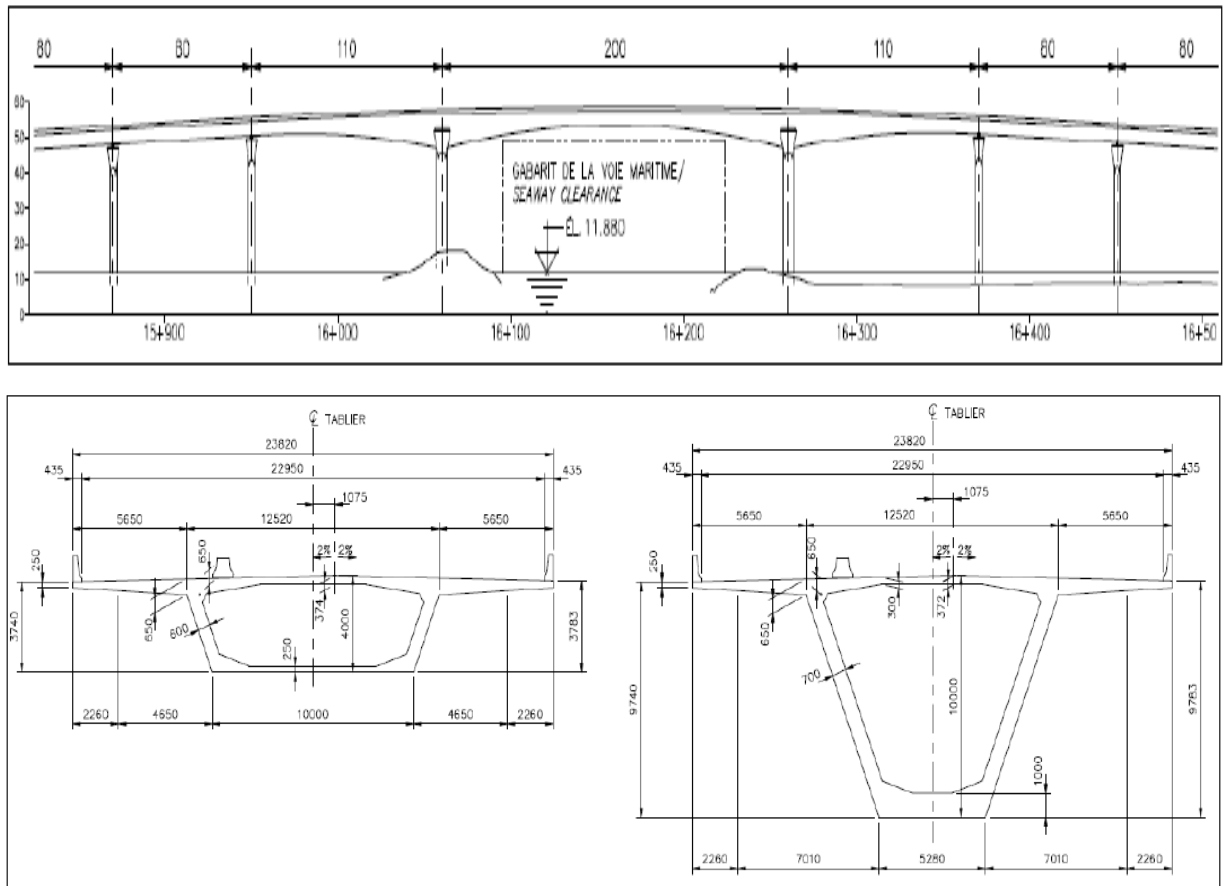
#### **4.2.1 A New Champlain Bridge Proposed**

As previously mentioned, there are five proposed designs for a new Champlain bridge:

- A. A prestressed concrete box girder bridge.

In the model shown below, the length of the seaway crossing is 200 meters, and the standard spans are each 110 and 80 meters. Moreover, the construction of this type of bridge was proposed by successive cantilevers ([Ministry of Transports Quebec, 2011](#)). The advantages of this proposed design are its resistance to twisting, as well as the ability to hold over a long stretch, such as the length of the Champlain Bridge. Moreover, a prestressed concrete box girder bridge is considered one of the bridges that has the most strength for use. The disadvantages of this proposed design needs additional costs, and the model production is too expensive because of difficult to access the area inside the Box ([Begum, 2010](#)).

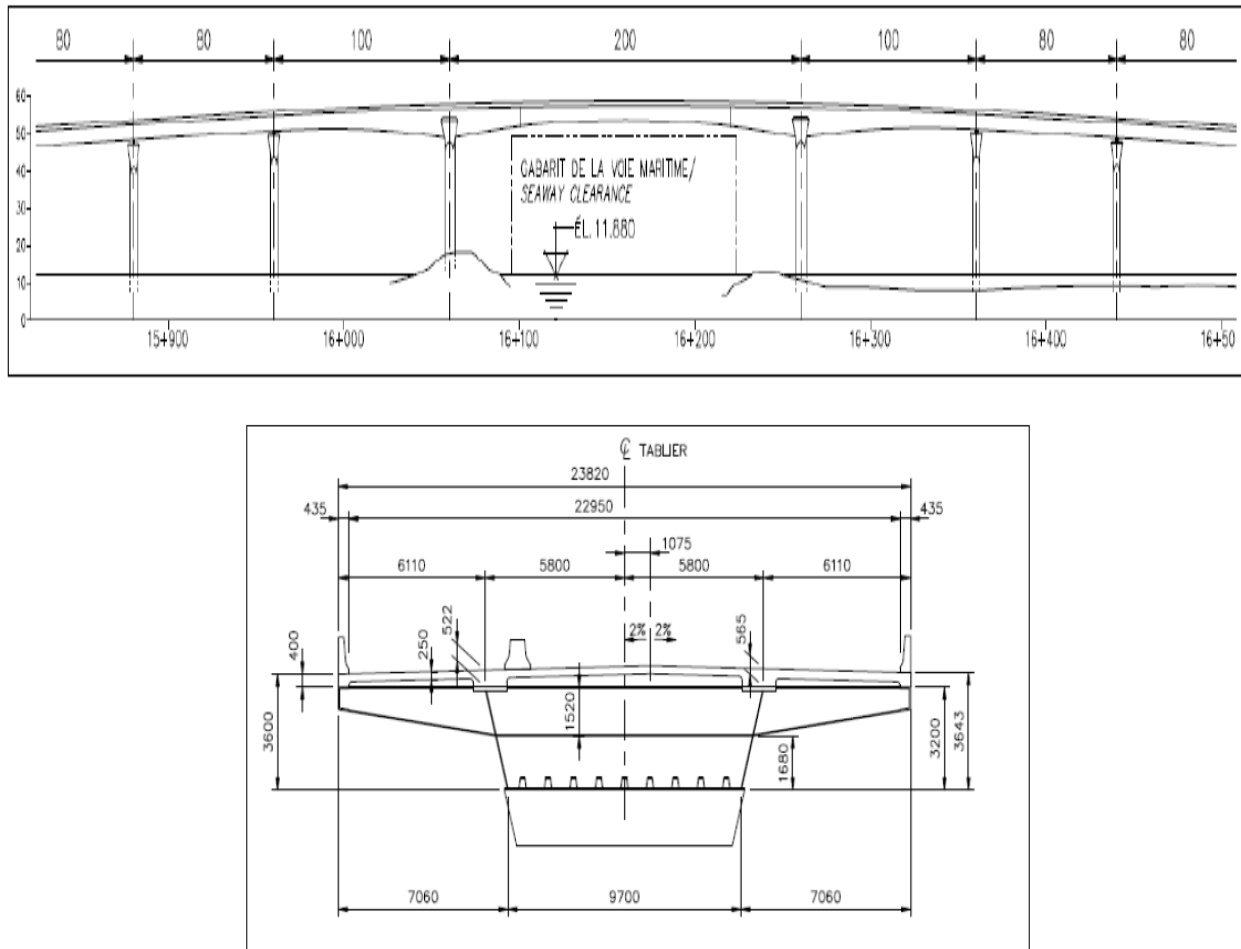




**Figure 4.3: A prestressed concrete box girder bridge (Ministry of Transports Quebec, 2011)**

B. A hybrid steel-concrete bridge.

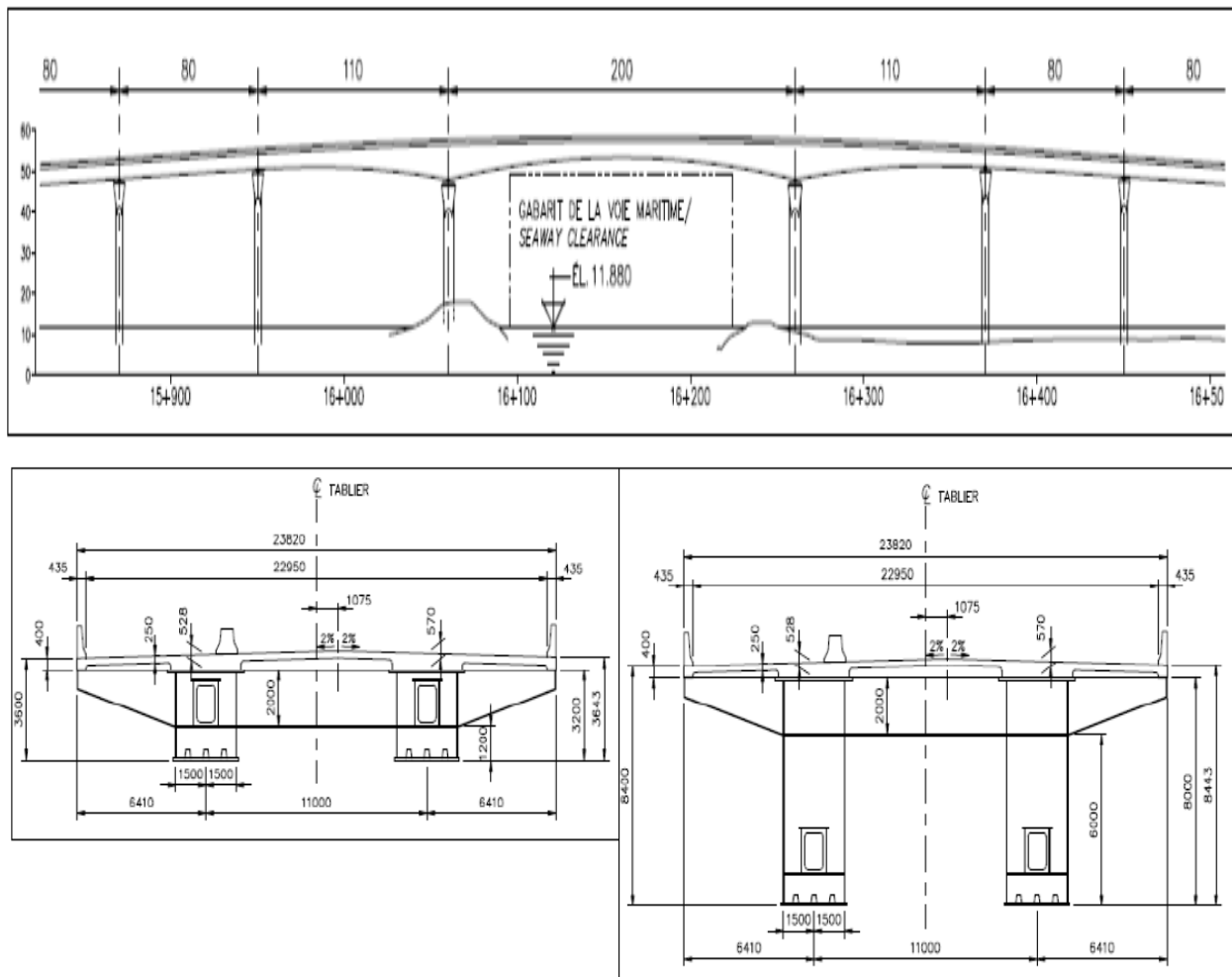
Figure 4.4 shows a hybrid steel-concrete bridge option, where construction of this proposed type includes hoisting and overhang. The length of the seaway crossing is 200 meters, and the standard spans are each 110 and 80 meters (Ministry of Transports Quebec, 2011). Moreover, the advantages of this proposed model are that it reduces the load on the bridge and features a light deck, while the disadvantage of this proposal is that the construction has a sensitivity in the connection between the concrete and the mineral sections (Ministry of Transports Quebec, 2011).



**Figure 4.4: A hybrid steel-concrete bridge** (Ministry of Transports Quebec, 2011)

#### C. A composite bridge.

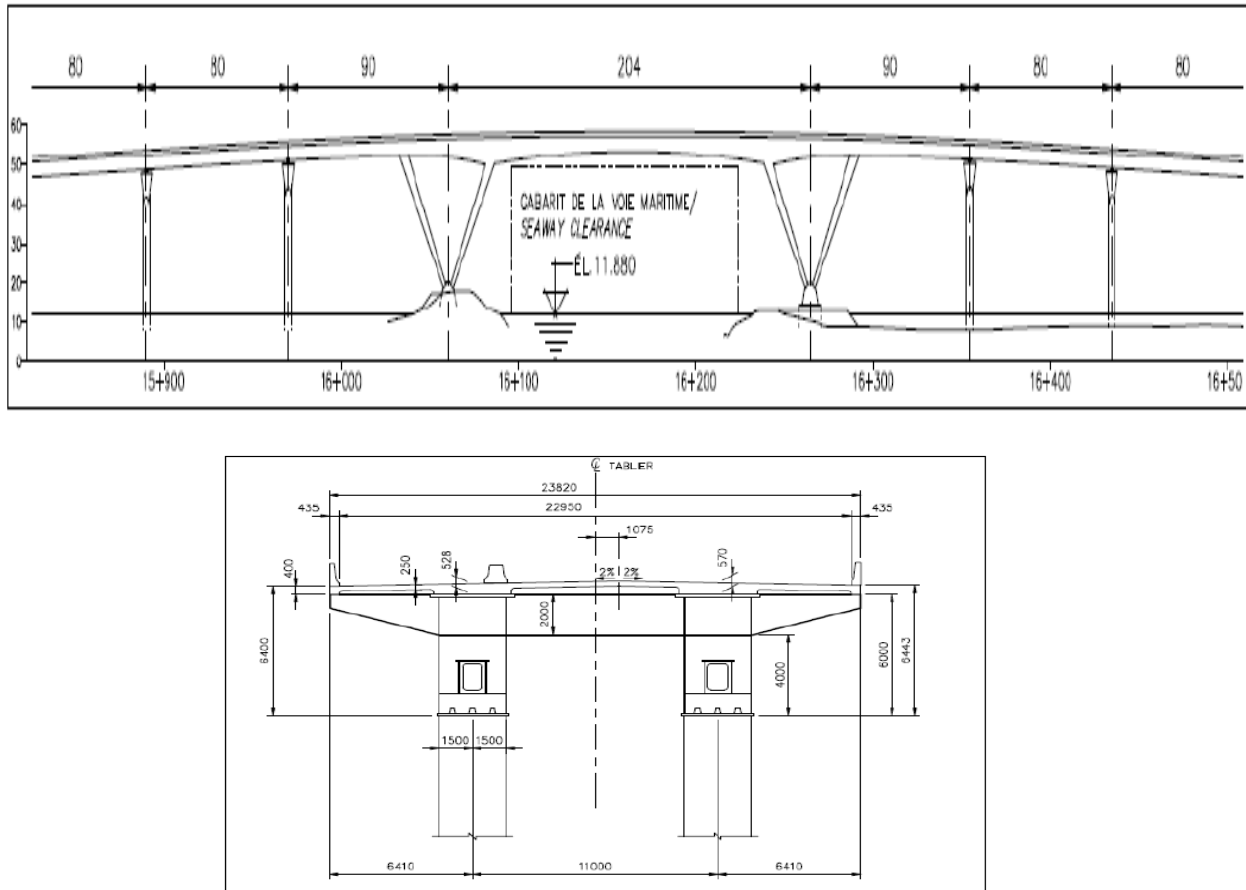
Figure 4.5 illustrates the third proposed type, where the length of the seaway crossing is 200 meters, and the standard spans are each 110 and 80 meters. The construction of this type of bridge is proposed by double girder (Ministry of Transports Quebec, 2011). However, the disadvantage of this proposed design are that it is too expensive, its fire resistance is low, the composite structural systems, as well as the lack of competencies for its maintenance. While the advantages of this design are that it reduces the loads on the bridge, features a light deck, and the materials used are corrosion-resistant (Plecnik & Henriquez, 2000).



**Figure 4.5: A composite bridge** (Ministry of Transports Quebec, 2011)

D. A composite bridge with V-shaped piers on both shores of the seaway.

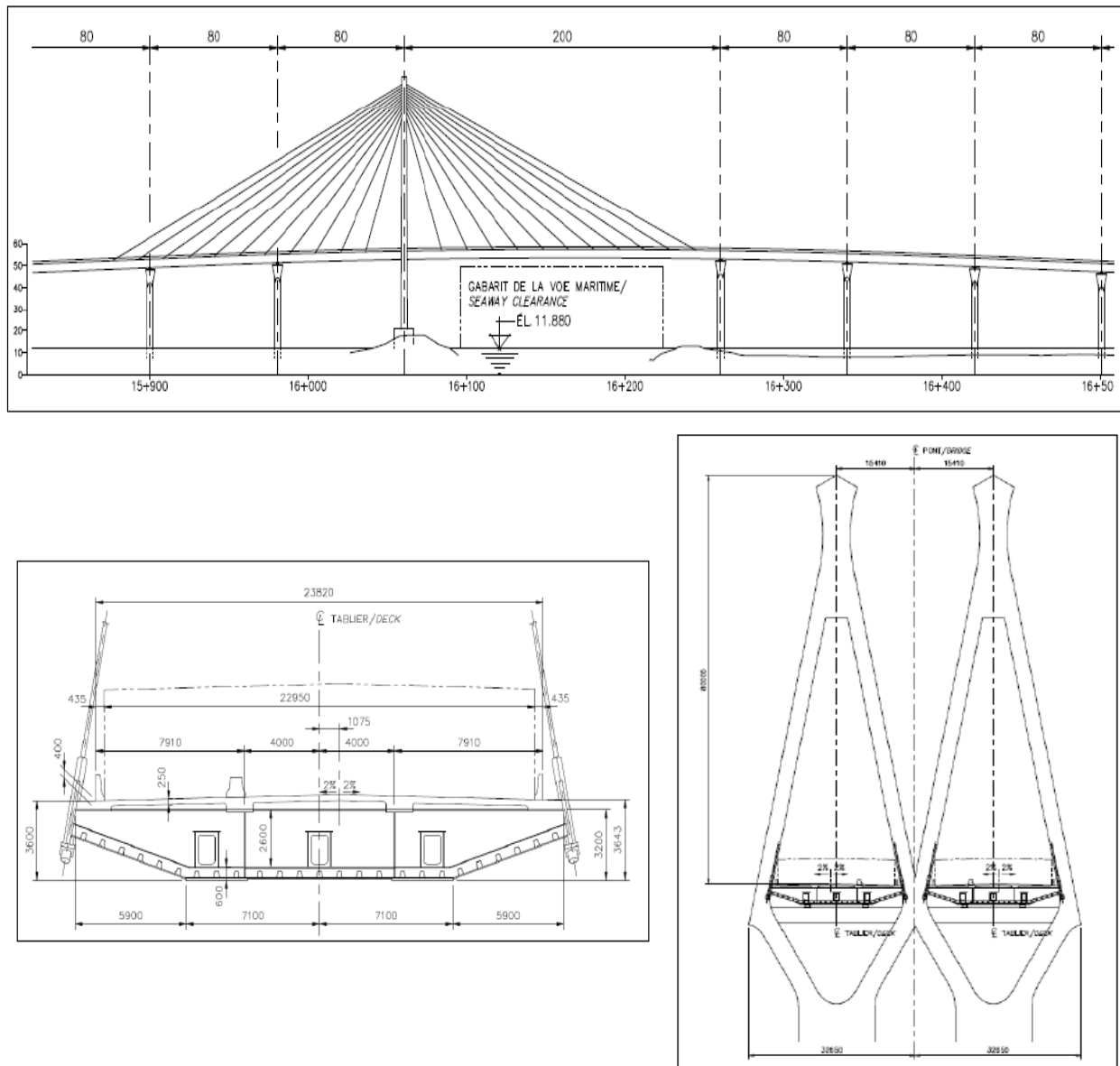
A composite bridge with V-shaped piers on both shores of the seaway as shown in Figure 4.6 illustrates a seaway crossing length of 204 meters, where the standard spans are each 90 and 80 meters. The construction of this type is proposed by double girder (Ministry of Transports Quebec, 2011). The disadvantage of this proposed design are that its implementation is complex because it depends on the composite pillar shaped like a "V", while the advantages of this proposed model are that it reduces the loads on the bridge and features a light deck, in addition to having a good visual effect (Ministry of Transports Quebec, 2011).



**Figure 4.6: A composite bridge with V-shaped piers on both shores of the seaway**  
(Ministry of Transports Quebec, 2011)

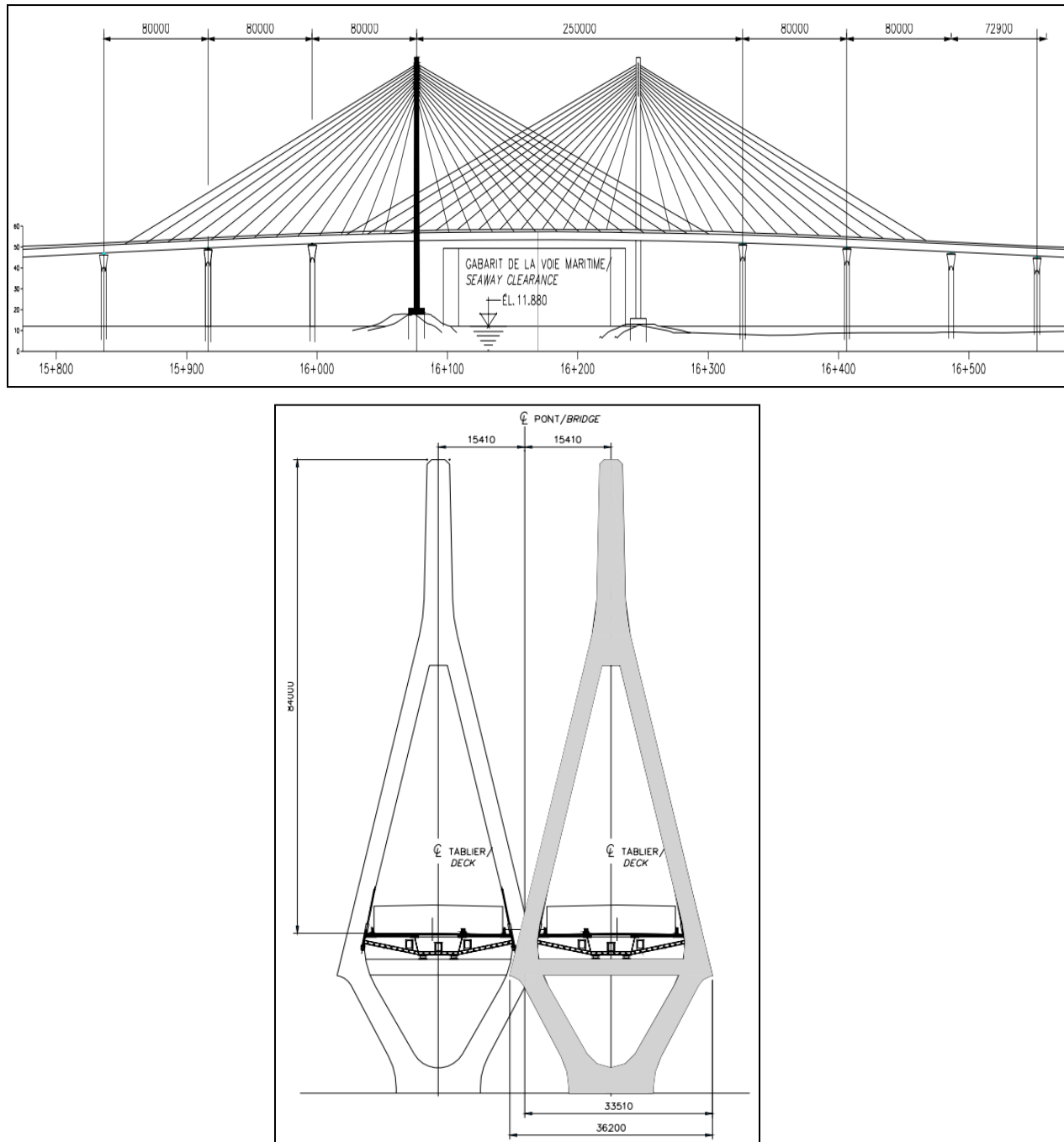
E. A composite cable-stayed bridge.

The model shown below displays a single pylon cable-stayed bridge. This model includes a single tower with two columns, with a seaway length crossing of 200 meters, and the standard spans are each 80 meters (Ministry of Transports Quebec, 2011). This model considered to be the best architectural model, and the advantages of this proposed model are that it features a breathtaking view and reduces the load on the foundations by screwing "cables". It also features a light deck, but the disadvantages of this proposed model are that it is one of the bridges that is considered the most complex for implementation cables (Ministry of Transports Quebec, 2011).



**Figure 4.7: A single pylon cable-stayed bridge (Ministry of Transports Quebec, 2011)**

Moreover, Infrastructure Canada has proposed another type of bridge infrastructure for a composite cable-stayed bridge as shown in the model below. This two pylons cable-stayed bridge is modeled by two separate towers with two foundations, with a seaway length crossing of 250 meters, and standard spans are each 72.9 and 80 meters (Ministry of Transports Quebec, 2011). This model is considered to be the best architectural model.



**Figure 4.8: Two pylons cable-stayed bridge** (Ministry of Transports Quebec, 2011)

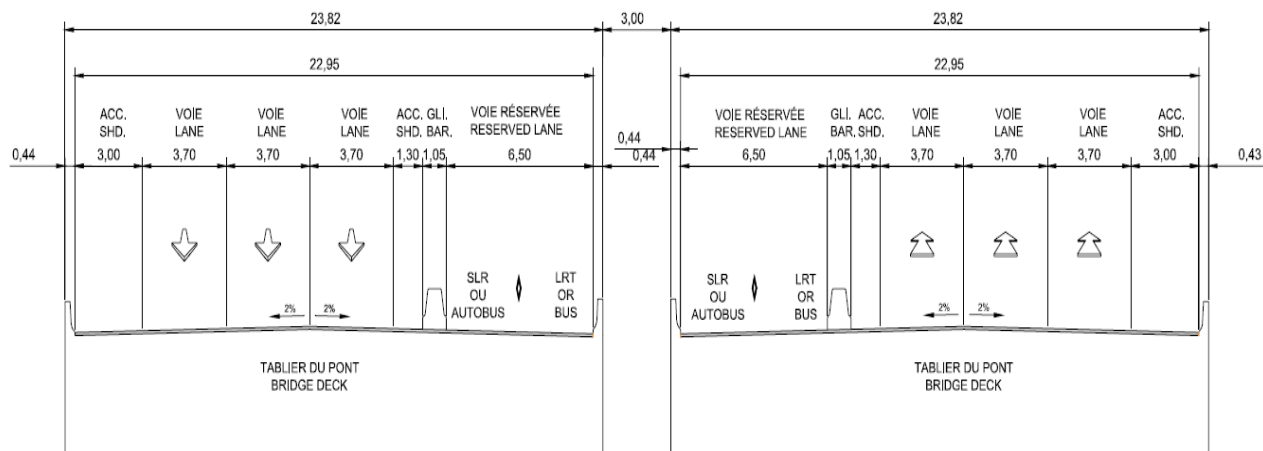
## 4.2.2 Deck Proposed for A New Champlain Bridge

Infrastructure Canada also proposed different deck designs for a New Champlain Bridge, with variations in the number of lanes and in lanes width, which are explained as follows:

A. Three lanes and ELPT in both directions.

As shown in Figure 4.9, the design deck has a width of 23.82 meters. This deck includes three lanes, where each lane's width spans 3.7 meters. This measurement will provide safety and comfort to its users. Not only is this type of deck designed for vehicles and trucks, but a specific lane is also present for buses in both directions with a width of 6.5 meters. Moreover, there are shoulders on both sides of the exterior lanes in both directions, with a width of 1.3 and 3 meters. This design will allow for comfortable traffic conditions as well as suitable speeds for drivers on the New Champlain Bridge ([Ministry of Transports Quebec, 2011](#)).

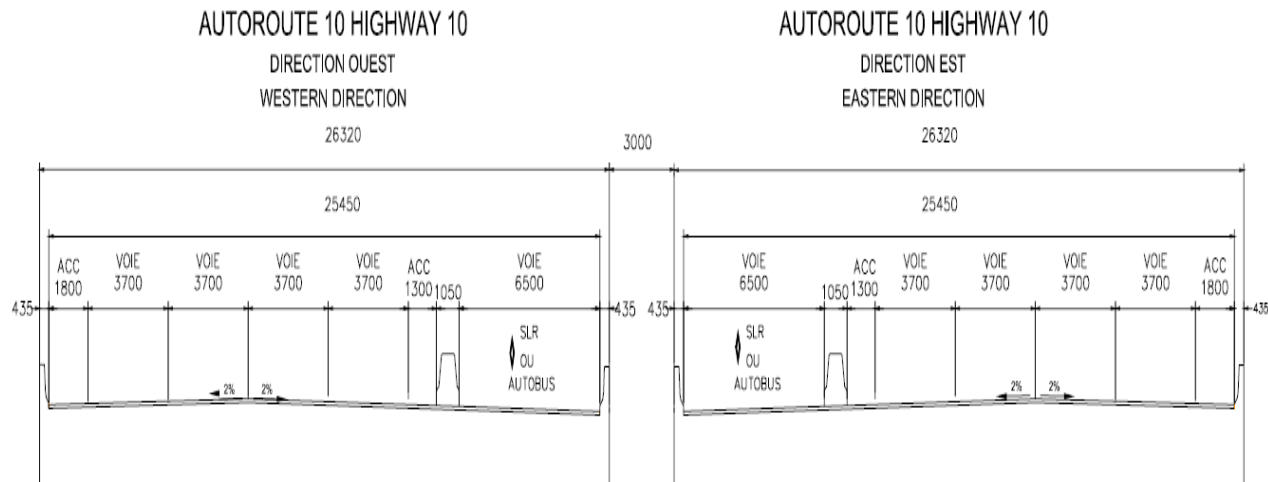
According to this proposed design the accidents and congestion on a new bridge will be less than they presently are.



**Figure 4.9: Three lanes and ELPT in both directions** ([Ministry of Transports Quebec, 2011](#))

B. Four lanes and ELPT in both directions

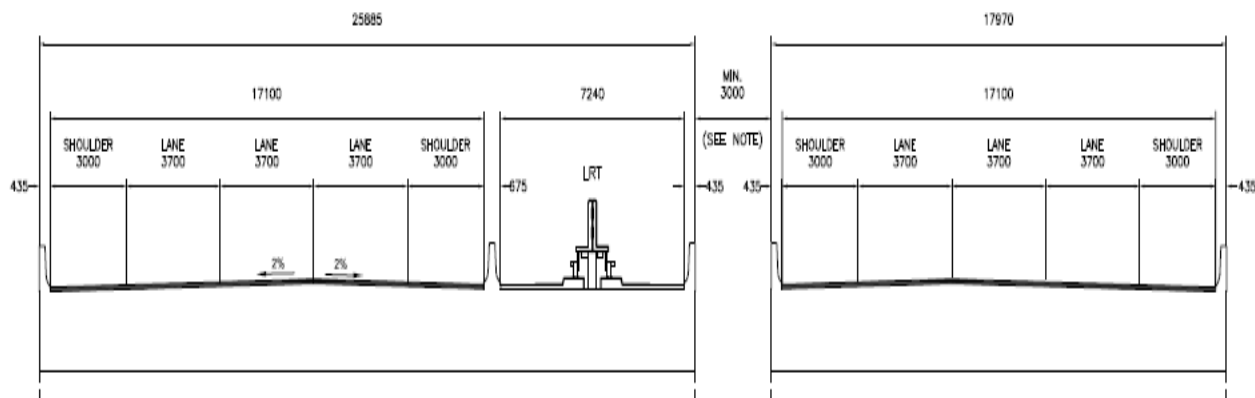
In this proposed design, a deck width is presented to be 26.32 meters, as shown in Figure 4.10. This deck includes three lanes, where each lane's width is 3.7 meters for vehicles and trucks, including shoulders on the left and right sides of the bridge. The width of the shoulders are 1.3 and 1.8 meters. Moreover, specific lanes will be attributed to buses in both directions, with widths of 6.5 meters ([Ministry of Transports Quebec, 2011](#)).



**Figure 4.10: Four lanes and ELPT in both directions** (Ministry of Transports Quebec, 2011)

C. Three lanes per direction with LRT:

This proposed design deck has a width of 17.97 meters in the Northern direction, while the deck width in the Southern direction is 25.885 meters. This deck includes three lanes, where each lane's width is 3.7 meters for vehicles and trucks, as well as shoulders on the left and right sides, where the shoulder width is 3 meters. However, there are two lanes specifically designed for LRT on the left deck side with a width of 7.24 meters, as shown in Figure 4.11.



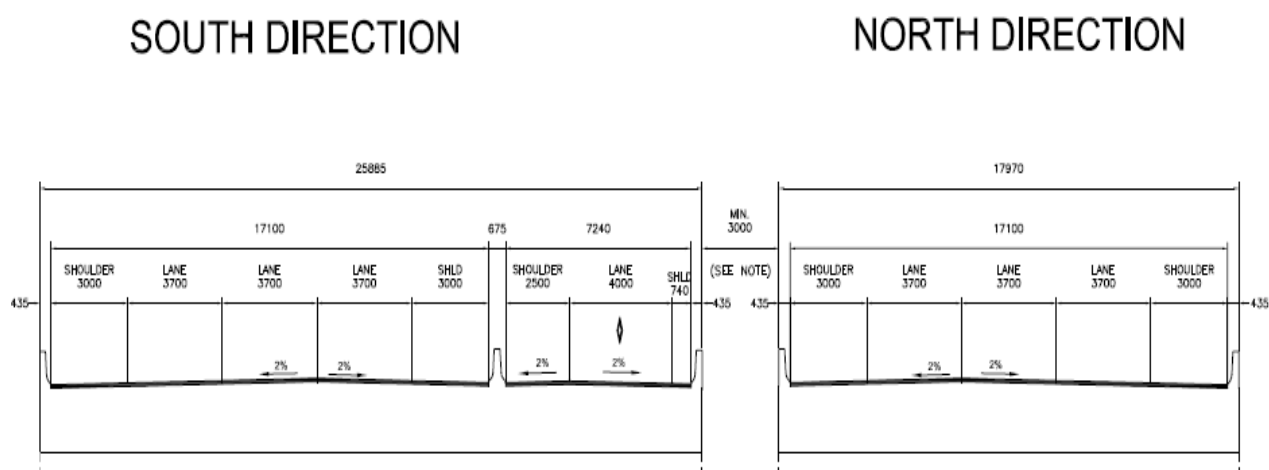
**Figure 4.11: Three lanes per direction with LRT** (Ministry of Transports Quebec, 2010)

D. Three lanes per direction:

This proposed design deck involves a width of 17.97 meters in the Northern direction, while the deck width in the Southern direction is 25.885 meters. This deck includes three lanes for vehicles and trucks with a width of 3.7 meters, and shoulders on both the left and right sides, with a shoulder width of 3 meters. Moreover, there are two lanes attributed to buses on the left deck side



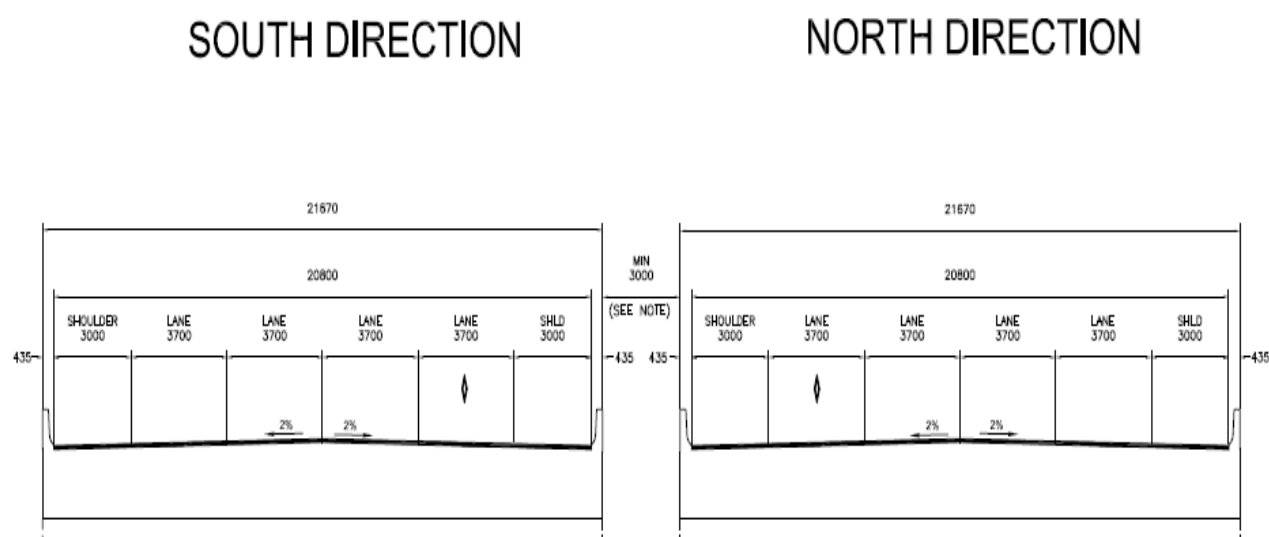
with a width of 7.24 meters, including two shoulders, with widths of 2.5 meters and 0.74 meters, as shown in Figure 4.12.



**Figure 4.12: Three lanes per direction** (Ministry of Transports Quebec, 2010)

E. Three lanes per direction:

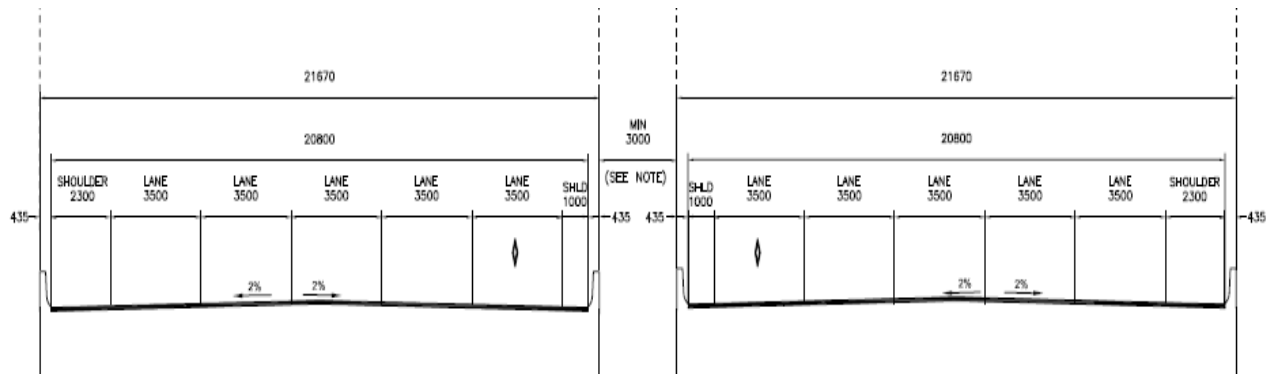
This proposed design has a deck width of 21.67 meters. This deck includes three lanes, where each lane's width is 3.7 meters for vehicles and trucks, in addition to shoulders on the left and right sides with a width of 3 meters. As well as, there are two specific lanes designed for buses going in both directions with a width of 3.7 meters, as shown in Figure 4.13.



**Figure 4.13: Three lanes per direction** (Ministry of Transports Quebec, 2010)

F. Four lanes per direction:

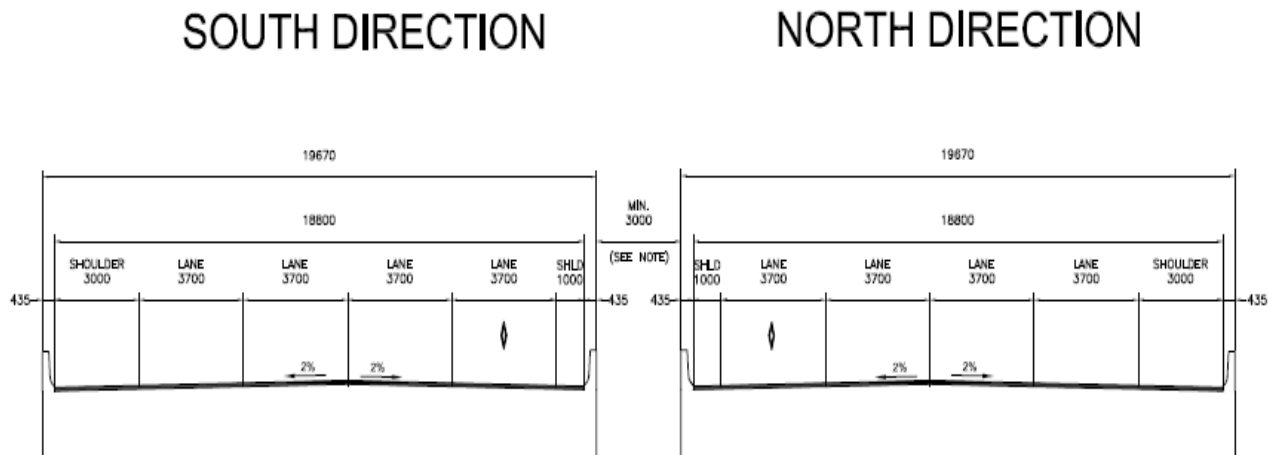
This model proposes a design deck width of 21.67 meters. The deck includes four lanes, where each lane's width is 3.5 meters for vehicles and trucks. Moreover, there are two shoulders on the left and right sides with a width of 2.3 meters and 1 meter. Two lanes are specifically designed for buses going in both directions with a width of 3.5 meters, as shown in Figure 4.14.



**Figure 4.14: Four lanes per direction** (Ministry of Transports Quebec, 2010)

G. Three lanes per direction:

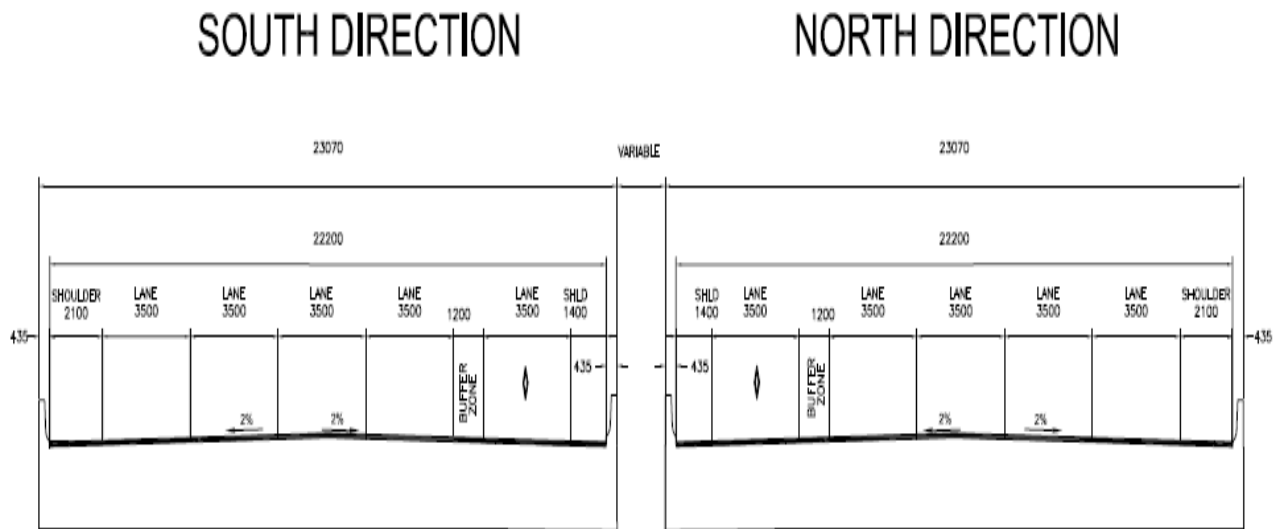
This model proposes a deck width of 19.67 meters, which includes three lanes, each with a width of 3.7 meters for vehicles and trucks, as well as two shoulders on both the left and right sides with widths of 3 meters and 1 meter. There are, however, two lanes specifically designed for buses going in both directions with a width of 3.7 meters, as shown in Figure 4.15.



**Figure 4.15: Three lanes per direction** (Ministry of Transports Quebec, 2010)

#### H. Four lanes per direction:

Figure 4.16 illustrates a model with a deck width of 23.07 meters, which includes three lanes, where each lane's width is 3.5 meters for vehicles and trucks. This design also includes two shoulders on both the left and right sides with widths of 2.1 meters and 1.4 meters. Furthermore, there are two lanes specifically designed for buses driving in both directions with a width of 3.5 meters. Furthermore, a buffer zone with a width of 12 meters is presented in both directions among buses and vehicles.



**Figure 4.16: Four lanes per direction** (Ministry of Transports Quebec, 2010)

### 4.2.3 Design Speedway Curve

The existing Champlain Bridge has a steep slope over the St. Lawrence crossing. Therefore, Infrastructure Canada has taken responsibility to improve the longitudinal slope by four or eight meters, depending on the structure that will be used to build the Seaway, as shown in Figure 4.17. This development will allow for the optimization of traffic movement over the curve (Ministry of Transports Quebec, 2011).

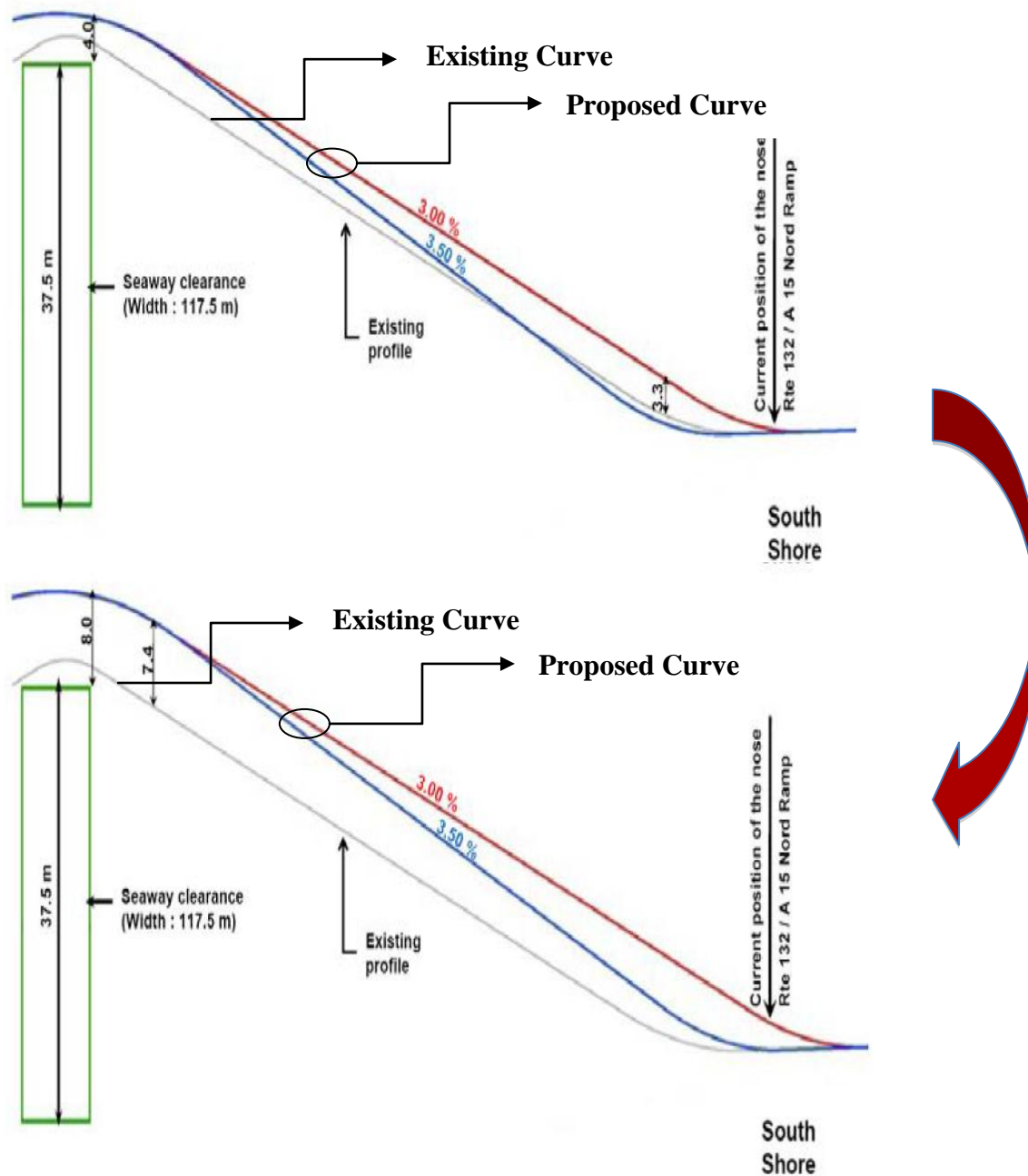


Figure 4.17: Design speedway curve (Ministry of Transports Quebec, 2011)

## 4.2.4 Preliminary Analysis

We developed a comparison between various proposed designs suggested in the Request for Proposals (RFP) publically made available by Infrastructure Canada for a New Champaign Bridge. There are five proposed designs that vary in price, features, advantages, disadvantages, etc. A detailed description of these designs is presented in Table 4.1. At the moment, it should be noted that the exact design and details of the bridge are not finalized. Consequently, our implementation of the BIM is only based on assumptions. Table 4.2, Figure 4.18, and 4.19 represents the analysis of our initial conclusions and suggest that a cable-stayed bridge design scores highest and is the most favourable option.

**Table 4.1: Comparison of alternatives** (Ministry of Transports Quebec, 2011)

No table of figures entries found	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 is 80 meters and the deck width in both directions is 23.82 meters				
Description – Seaway	Single box of prestressed concrete or a composite of steel and reinforced concrete. This option is built by balanced cantilever (Begum, 2010).	This model is a combination of concrete and steel, as is the case in the existing bridge	This model of seaway depends to the composite pillar	This model of seaway depends on the composite pillar on shaped "V"	The seaway depends on the cables that are composite on a 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	This model is designed to last a short period of time, frequently on the seaway	The seaway closed in the installation span	This model is designed to last a short period of time, frequently on the seaway. A closed box-girder will lead to the cancellation corresponding constraints.	This model is designed to last a short period of time frequently on the seaway. A closed box-girder will lead to the cancellation corresponding constraints, and the seaway is closed in the installation span.	This model is designed to last a short period of time, frequently on the seaway and A closed box-girder will lead to the cancellation corresponding constraints, and the seaway is closed in the installation span.

**Table 4.1: Comparison of alternatives (Ministry of Transports Quebec, 2011) (Continued)**

No table of figures entries found	Concrete single box	Hybrid steel-concrete	Composite Superstructure bridge for twin girders and boxes	Composite Superstructure bridge with V shaped	Cable-stayed bridge
Construction cost  (With contingencies)	The cost of this proposal is CAD \$830 million	The cost of this proposal is CAD \$895 million	The cost of this proposal for twin girders is CAD \$775 million, while boxes is CAD \$910 million.	The cost of this proposal is CAD \$910 million	The cost of this proposal is CAD \$910 million
Operating and maintenance cost	Each model is facing different problems, moreover, the solution to these problems are almost similar				
Construction time	The Construction time is almost the same for all models				
Environmental effects	Reduces number of piers compared to the existing bridge that will generate a better environment than existing the 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 attraction for tourism	Model has no attraction for tourism	Model has no attraction for tourism	Model has no attraction for tourism	Model does have an attraction for tourism
Advantages	Resistance to twisting, has ability to a long stretch, and strong for uses (Begum, 2010).	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 have corrosion-resistant (Plechnik & Henriquez, 2000).	This model reduces the loads on the bridge and features a light deck, and has a good visual effect	Featuring a breathtaking view and reduces loads on foundations by screwing "cables". It also features a light deck
Disadvantages	Additional costs, and the model production is expensive (Begum, 2010)	The construction has a sensitive connection between the concrete and the mineral sections	Too expensive, fire resistance is low, and the composite structural systems as well as the lack of competencies for maintenance (Plechnik & Henriquez, 2000).	This model is complex in the implementation because it depends on the composite pillar on the shaped "V"	Is one of the bridges that is considered complex for implementation "cables"

The table 4.2, shows the analysis for table 1. In this table we assume percentages and follow the scale: 0 - very unfavorable, 1 - unfavorable, 2 - less unfavorable, and 3 - favorable.

Therefore, according to our preliminary analysis as shown in table below, there is a large variance among the different proposals, whether that be aesthetics, by project cost, for construction constraints, or in terms of advantages and disadvantages. Therefore, architecturally, we note that the proposed cable-stayed bridge is considered the most aesthetically-pleasing, so this proposal may have a significant impact on the future ability to attract tourists to Montreal, because of the greatness of this project.

**Table 4.2: Comparison of alternatives** (Ministry of Transports Quebec, 2011)

	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							
	1 unfavourable							
	0 very unforable							

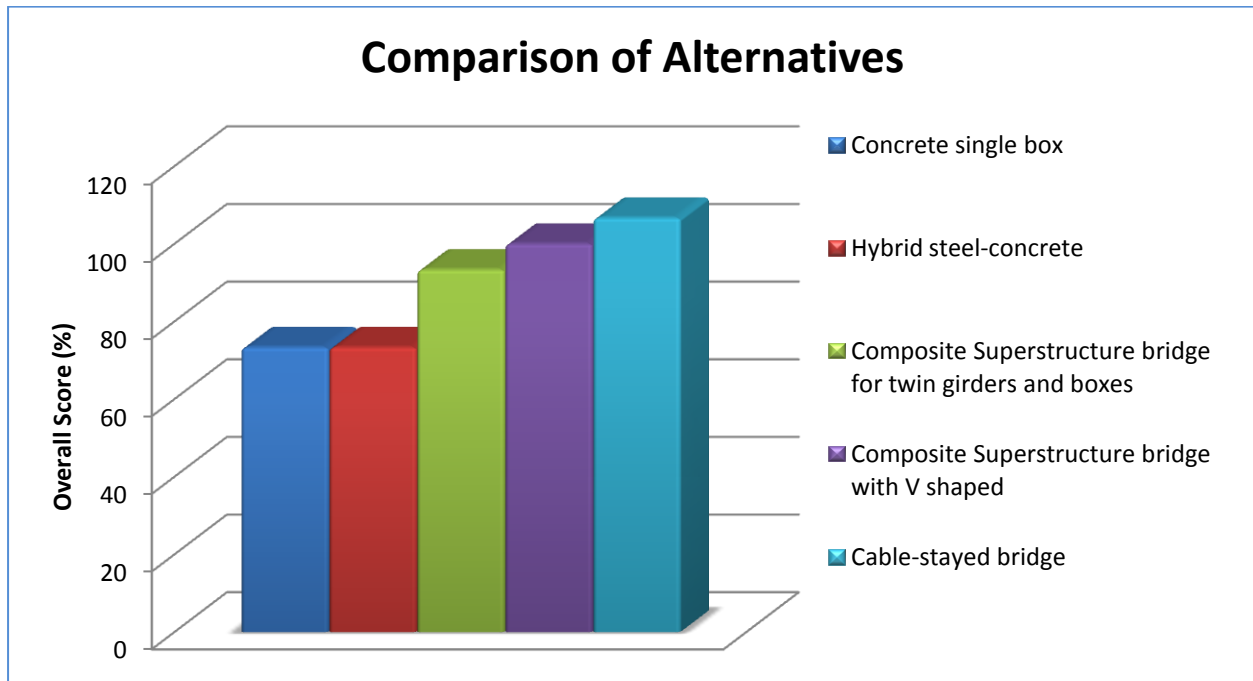
Chosen solution as it can become an icon form Montreal.

We noticed that there are advantages and disadvantages among these proposals, where the concrete single box and hybrid steel-concrete proposals have more disadvantages than the other proposals. For example, the concrete single box and hybrid steel-concrete proposals are difficult to repair because of the erosion of the steel cables in the proposed concrete single box (Begum, 2010). As well, the hybrid steel-concrete has a sensitive connection between the concrete and the mineral sections (Ministry of Transports Quebec, 2011). These disadvantages may have a significant impact in the long run, while the other proposals are considered less problematic. On the other hand, the composite superstructure bridge with a V shaped and cable-stayed bridge proposals have several great features such as a reduction of the loads on the bridge and a breathtaking view which would help attract tourists. In terms of cost, we note that there is a clear disparity in the total value of the proposals, which varies between CAD \$ 830 and 910 million

(Ministry of Transports Quebec, 2011). The costs do not include the maintenance point during its lifetime nor do they include the duration of funding.

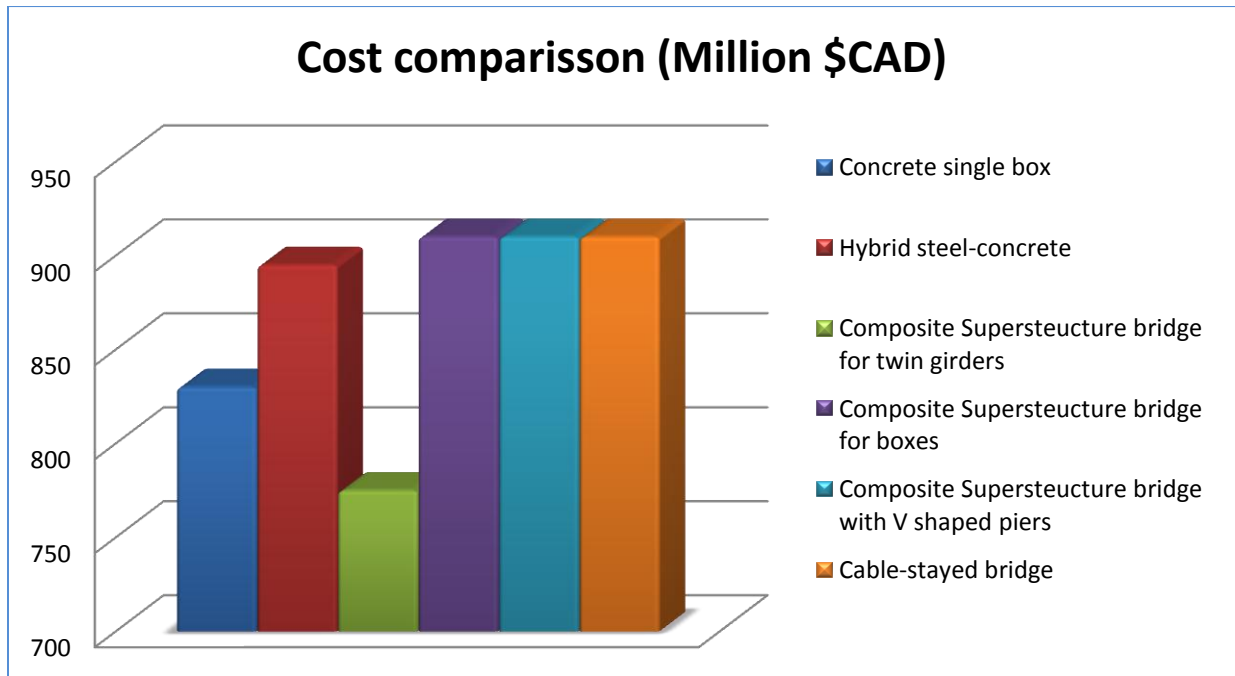
The cost for the Concrete single box and Hybrid steel-concrete proposals is around CAD \$ 830 million, whereas the difference in value between these proposals and the other proposals is almost CAD \$ 80 million (Ministry of Transports Quebec, 2011). This difference is considered too high, but this disparity is not resolved when we compare the advantages and disadvantages for Concrete single box and Hybrid steel-concrete proposed with other proposals. This is because the major factor when assessing bridges is long life-expectancy without facing any problems, which are features found in the Composite superstructure bridge with a V shape and the Cable-stayed bridge proposals.

Our initial descriptive analysis for a New Champlain Bridge shows us that the cable-stayed bridge proposal is the best in that it provides high features, which are better for a long life and can attract tourists to Montreal.



**Figure 4.18: Comparison of alternatives**





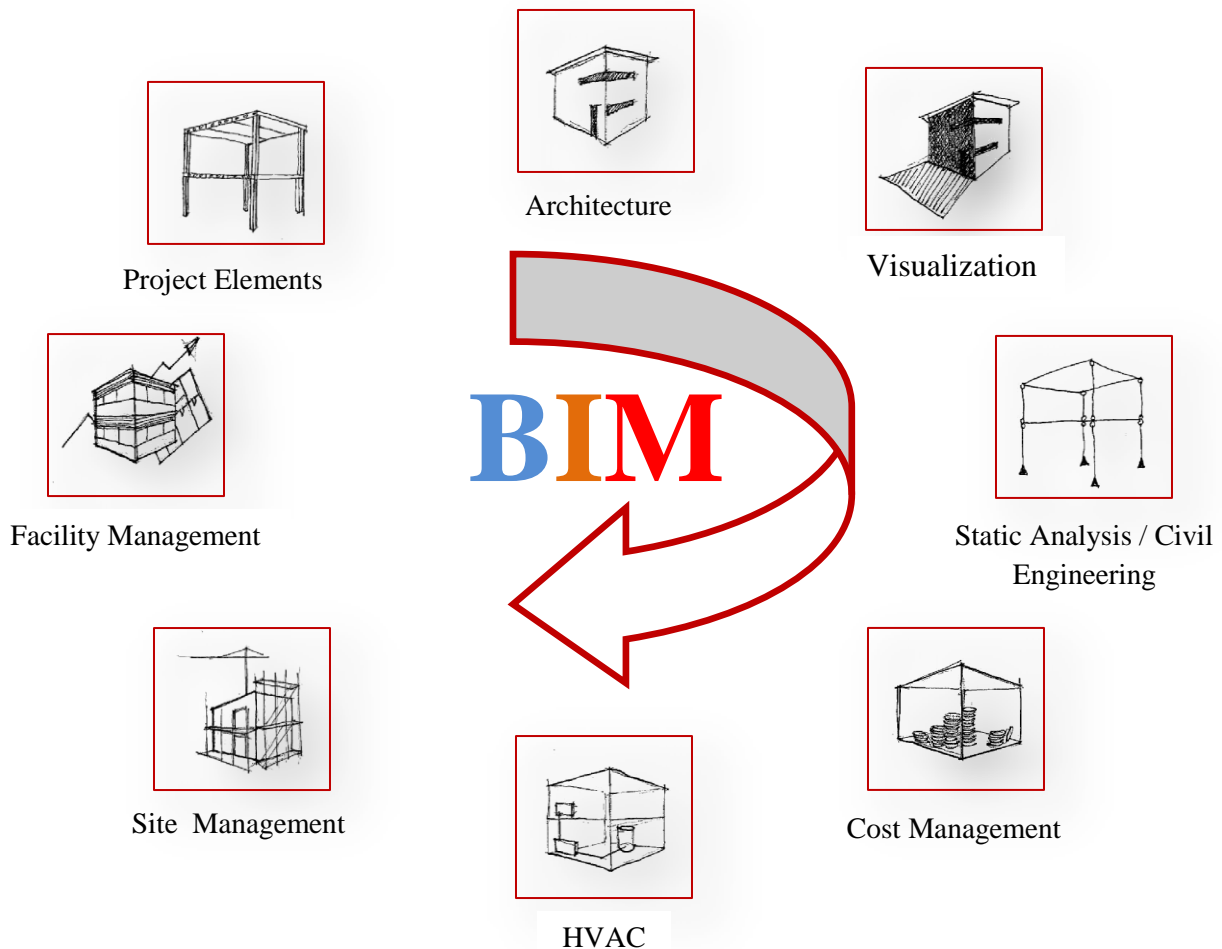
**Figure 4.19: Cost comparison (million \$CAD)**

The initial descriptive analysis of a New Champlain Bridge illustrates the difficulties in figuring out the problems, which may be faced during project implementation stages. Some issues include the inability to accurately know all project stages and problems that may lead to changes in the project time schedule. For example, the emergence of problems at the project site during the implementation stages such as an error in the columns and foundations site design, due to difficulties in finding out the project as in a real life scenario during the project design period. In relation to the problems of increased duration, the project cost during the implementation period may also be an issue. For example, as previously mentioned, when the project schedule changes, the project cost will increase. The cost will therefore not be accurate, as this system does not support the cost update automatically. Changing or modifying the project takes time because this system doesn't integrate all the information in one model. BIM will provide a solution to address these problems by providing a system that shows us all the project stages before the project implementation including time and cost. As well, the system will update the cost estimation for each item, and will easily modify the project in short time. It is clear that BIM system has the ability to integrate all information in one model.

### 4.3 BIM System

A new Champlain Bridge has been designed by using the traditional method, which may lead to several problems in the long run. These problems will be apparent during project design, scheduling (project delivery), cost estimation, implementation etc. Moreover, owners or contractors will be unable to make quick decisions, as they will not have a clear vision of the project. In this project we used the "BIM" system because it is considered a system that has a high accuracy and quality design, implementation, as well as an excellent project delivery.

Our aim is to develop a BIM system that focuses on a 3D model as the foundation for the BIM system, a 4D models for scheduling and simulation, and a 5D models for cost estimation. We used Allplan for 3D visualization, Nevaris for cost estimation and TIM for scheduling and simulation to develop the BIM system. Figure 4.20 shows the lifecycle management of the project by the BIM system.



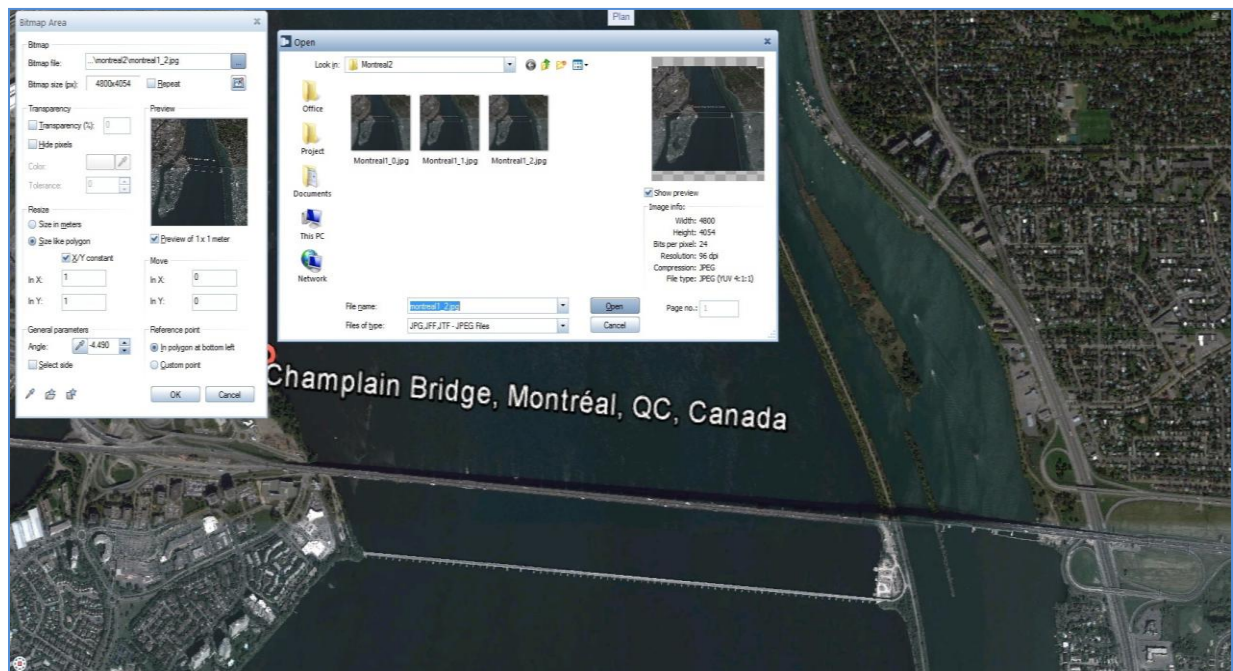
**Figure 4.20: BIM lifecycle for project stages (Schmeichel, 2013)**

### 4.3.1 3D Modelling: Visualization

The 3D modelling capabilities of Allplan were used for the rapid development of the model. 3D modelling provides easy modifications and changing of units without any inconsistencies. For example, if one wants to change or delete some columns, this can be performed on the 2D or 3D plan. The BIM will then automatically reflect the modifications in the entire project. At the design time, one chooses the material types that are dependent on the type of units and country codes of the specific location. Moreover, the 3D BIM supports 3D PDF, which is important to help the owners and contractors scrutinize the details of the project without resorting to downloading expensive software.

The details of 2D and 3D modelling using the BIM system for a New Champlain Bridge are as follows:

**Step 1:** Location and terrain are considered very important factors in order to determine the project site and the earth terrain, which can then determine the height of the bridge over the surface of the river level. We determined the location of the Champlain Bridge in Montreal using the Allplan software by importing a photo as a JPG file, as shown in Figure 4.21, then we modified the photo scale according to the existing Champlain Bridge length.

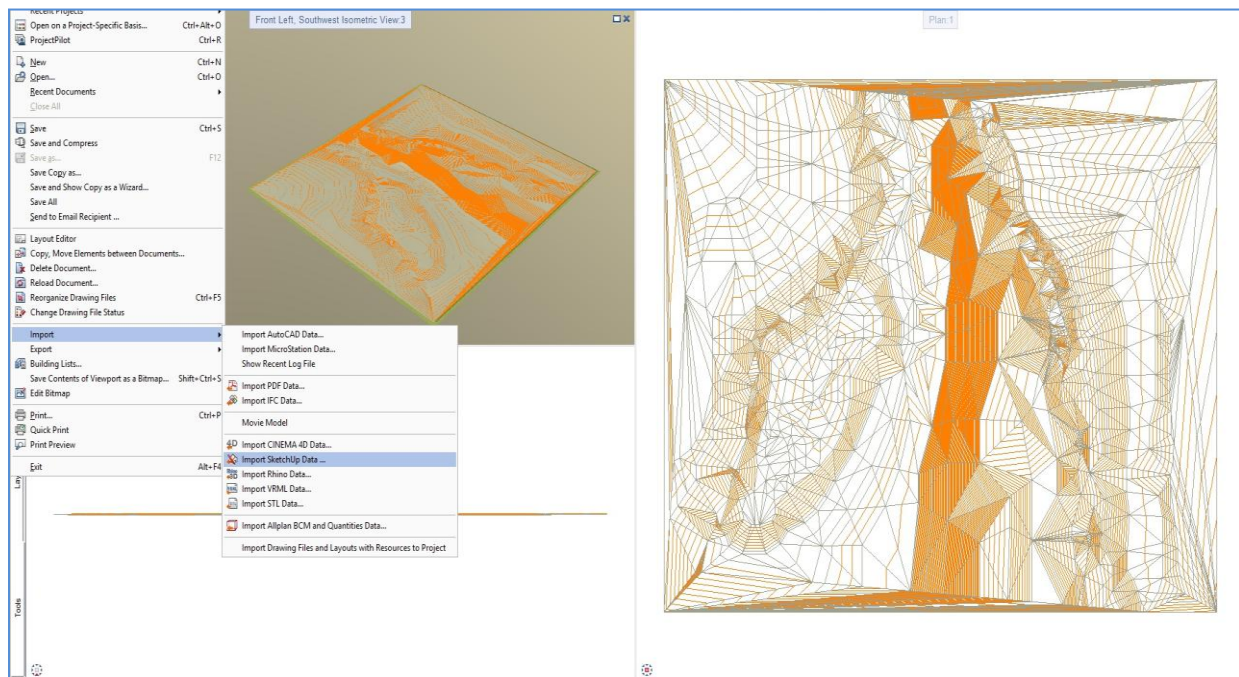


**Figure 4.21: Champlain Bridge location**

We faced an obstacle while determining terrain points, because the terrain was required to be modelled identically to reality in order to avoid problems during execution of the project foundations. We contacted Infrastructure Canada and asked them to support us by giving us these pointers, but they apologized for failing to provide us with this information. So, we identified terrain points by using a software that supports the BIM system. Softwares that support the BIM system (e.g. Allplan, Autodesk Revit, Tekla, ArchiCAD, etc) also support numerous approaches for modelling the real terrain. It can triangulate between 3D points, 3D terrain from DWG/DXF, and terrain from Google Earth/SketchUp.

In this study we used SketchUp software, because this software supports taking the terrain points directly from Google Earth in order to determine the location of the new Champlain Bridge in Montreal. This software depends on input data, which is the site address. Terrain points directly appear in the software, which provides Google Earth with the project site.

The information acquired (terrain) from the SketchUp software is then exported to the Allplan software to complete the project stages. Figure 4.22 shows the details of site terrains using Allplan software. The features of the BIM system are flexible if it is necessary to change or modify the terrain points.



**Figure 4.22: Terrain of Champlain Bridge**

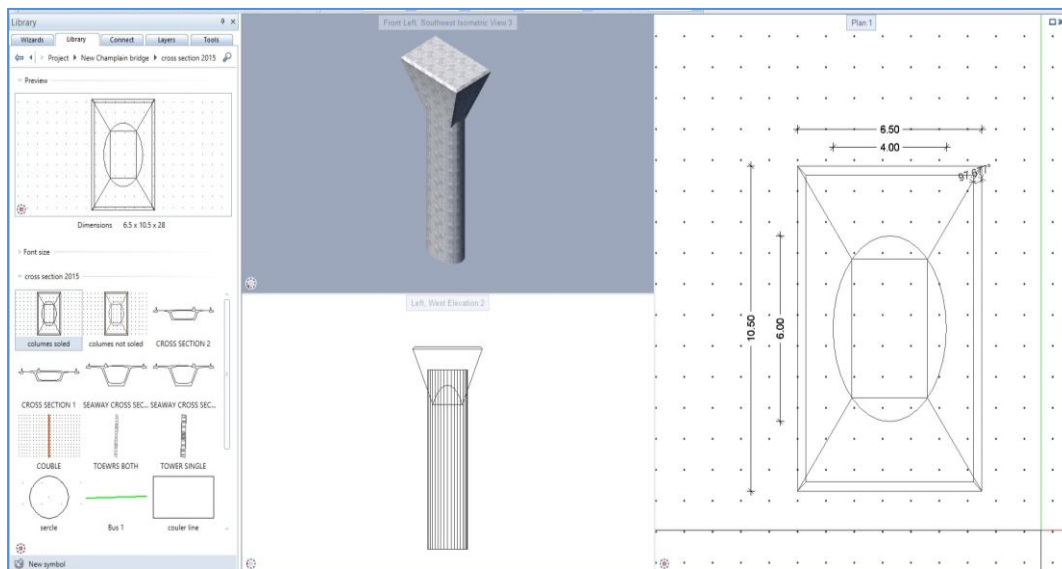


Figure 4.23 identifies the path of a New Champlain Bridge over the St. Lawrence River, with two lines located 10 meters North of the existing Champlain Bridge, according to Infrastructure Canada reports. In particular, these lines are considered to be the foundation for the bridge and they determine the locations of columns, towers, piles, etc.



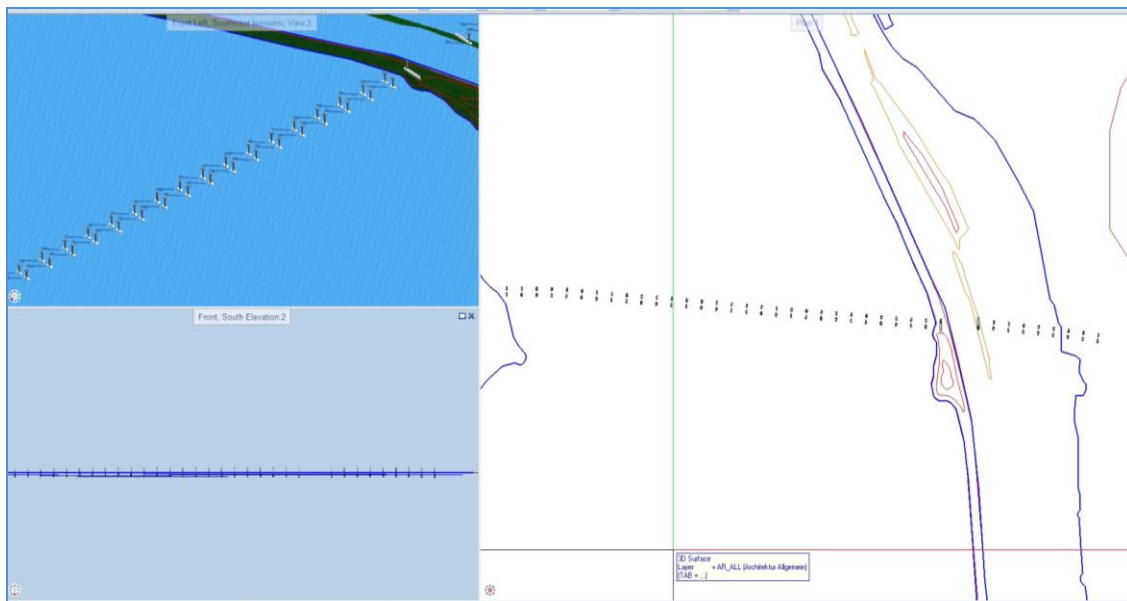
**Figure 4.23: The path of a New Champlain Bridge**

**Step 2:** Design piles, columns, and piers (2D & 3D model). As shown in Figure 4.24, using the BIM system depends on data input such as length, width, height and type of materials that are available in the system (such as concrete or steel etc.).



**Figure 4.24: Column design 2D & 3D**

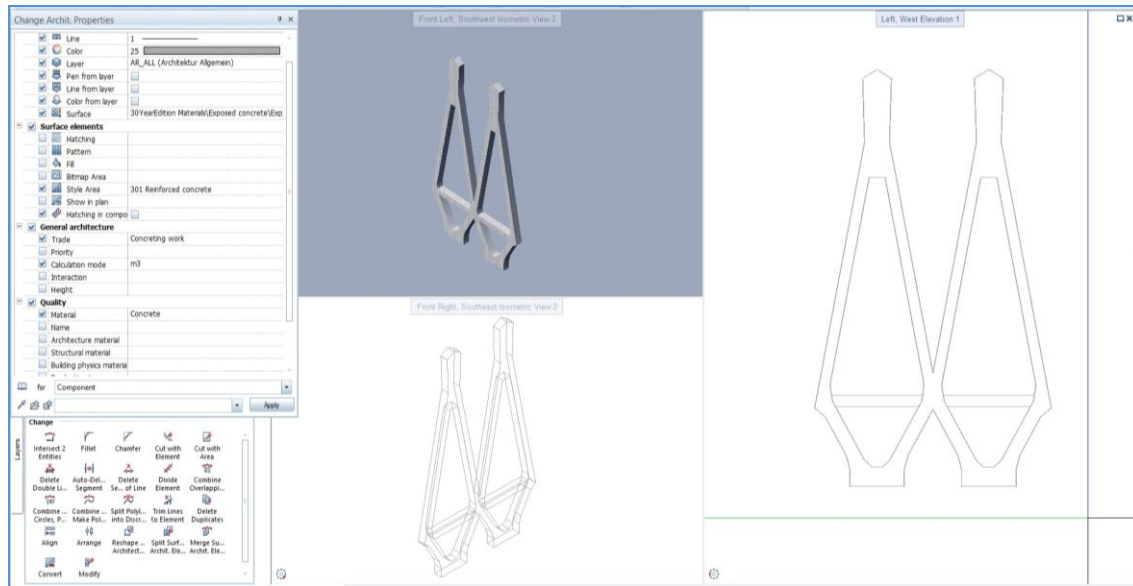
For example the details of column design depends on input data which includes the length and width of a column in order to get a 2D model and includes the height to get a 3D model, followed by materials type. If all columns in the project have the same format, BIM does not need to draw all columns one by one. BIM rather provides a system (offset) to draw all columns as well as other elements (e.g. piers, foundations, etc) in a short time, as shown in Figure 32. More features of using BIM include allowing the user to change or modify the model during the design period or during the project implementation period. The input data (length, width, height) according to Infrastructure Canada reports that these are available online.



**Figure 4.25: Copies piles, columns, and piers bridge on the path Red Line**

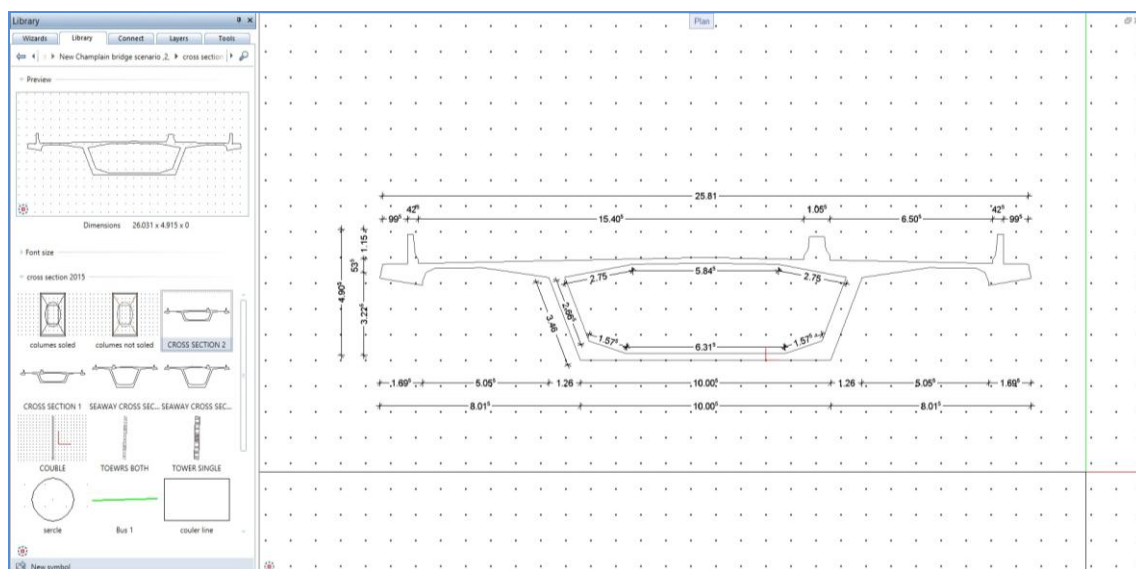
**Step 3:** Tower design. The data of tower design are determined according to the Infrastructure Canada reports. By using the BIM system, the tower design depends on the input of information (the width, height and angles) which allows for the visualization of the tower as a 2D model, as shown in Figure 4.26. As well, the 3D model can be obtained from the tower depth, and the type of materials can then be used in the model (e.g. concrete, precast concrete, etc).

BIM allows the user to verify the problems or any conflicts, which the tower may face during the implementation stage (e.g. an error in the rack design which carries the deck on the tower). The advantages of using BIM to design the tower of the bridge are its flexibility and its ease to change or modify the tower in short periods of time. As well, the vision of the tower as in a real life.



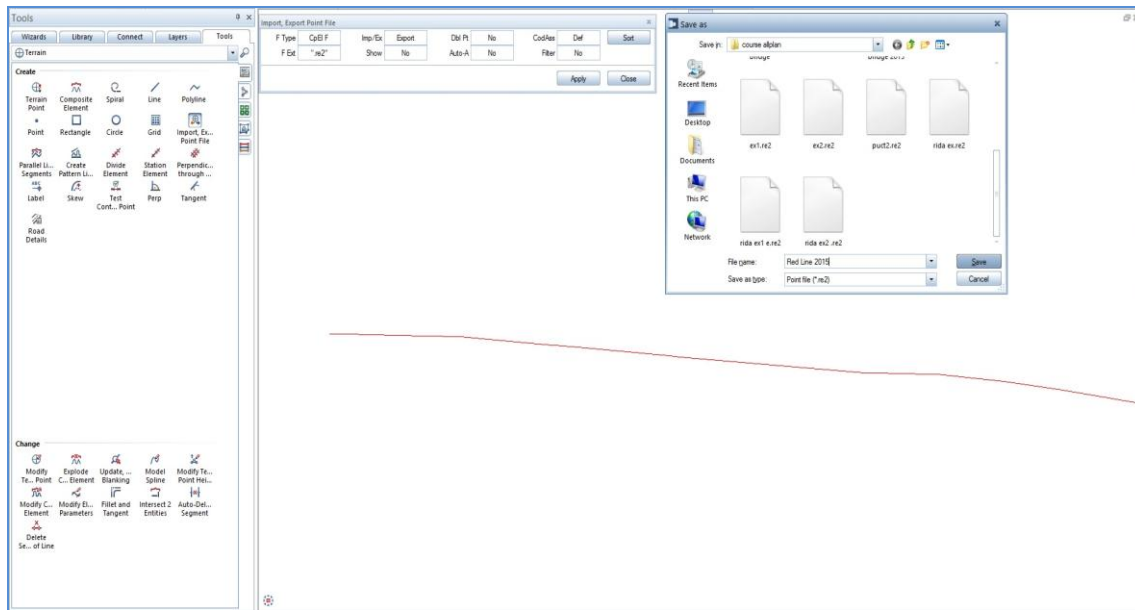
**Figure 4.26: Tower design**

**Step 4:** Linking two areas for traffic movement (vehicles, cyclists, train, and pedestrians) is considered an important part of the bridge as well. In this case study, we used the BIM system and we identified the deck details according to Infrastructure Canada reports. BIM system depends on input data which includes the width, height and angles which determine the 2D model. Figure 4.27 shows the deck details as a 2D model, the deck details (deck width of 23.82 meters) includes three lanes, each lane's width span (3.7 meters), and a lane for buses in both directions with a width of 6.5 meters. As well, it includes shoulders in both directions, with a width of 1.3 and 3 meters.



**Figure 4.27: Design for the front view of deck**

We used the Allplan software that support 2D and 3D model using BIM. The features of using BIM include its ability to communicate and collaborate among the stakeholders (e.g. designers, owner and contractors etc). This feature allows for flexibility in modifying and figuring out all project details during design period. By using the BIM system to design deck needs, we can determine the line known "Red Line" as shown in Figure 4.28.



**Figure 4.28: Digital terrain model**

The function of this line is to identify the path of the deck and change the deck model from a 2D to a 3D model by exporting a Digital Terrain Model (DTM) file as shown in Figure 4.28. This file transfers all Red Line data including length and curves for the bridge's design. This data provides a foundation which creates the complete bridge deck; moreover, this line divides into several points, as shown in Figure 4.30, and these points serve to modify or change the deck curve or to link two models which are different in size on a single line

Therefore, the Red line is an important step to start designing the bridge deck. Moreover, the BIM system has the flexibility design to create any complex model.



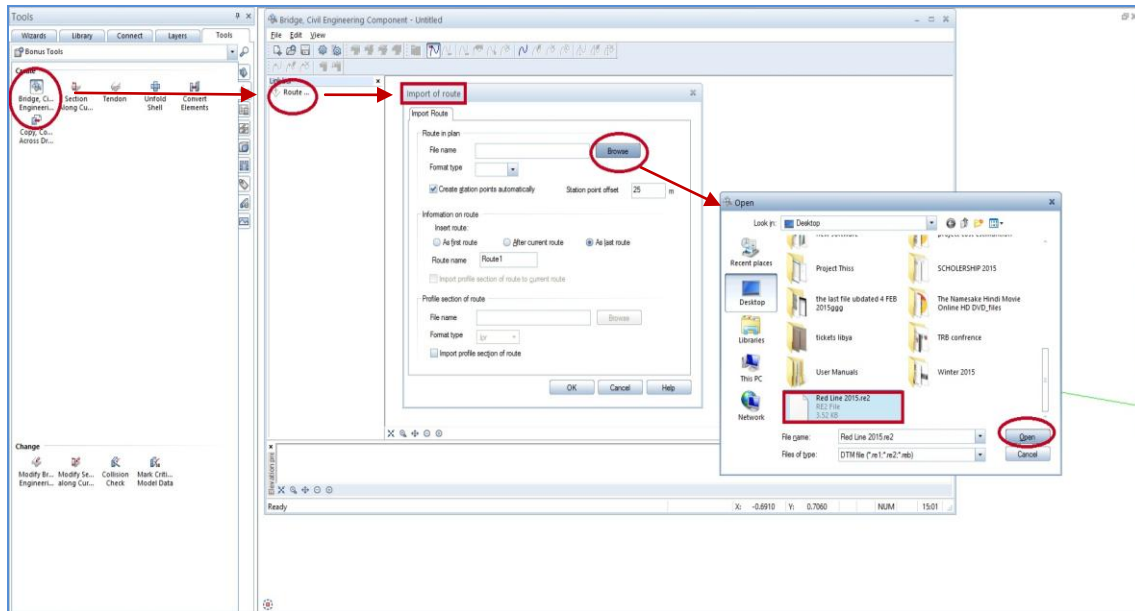


Figure 4.29: Export digital terrain model file

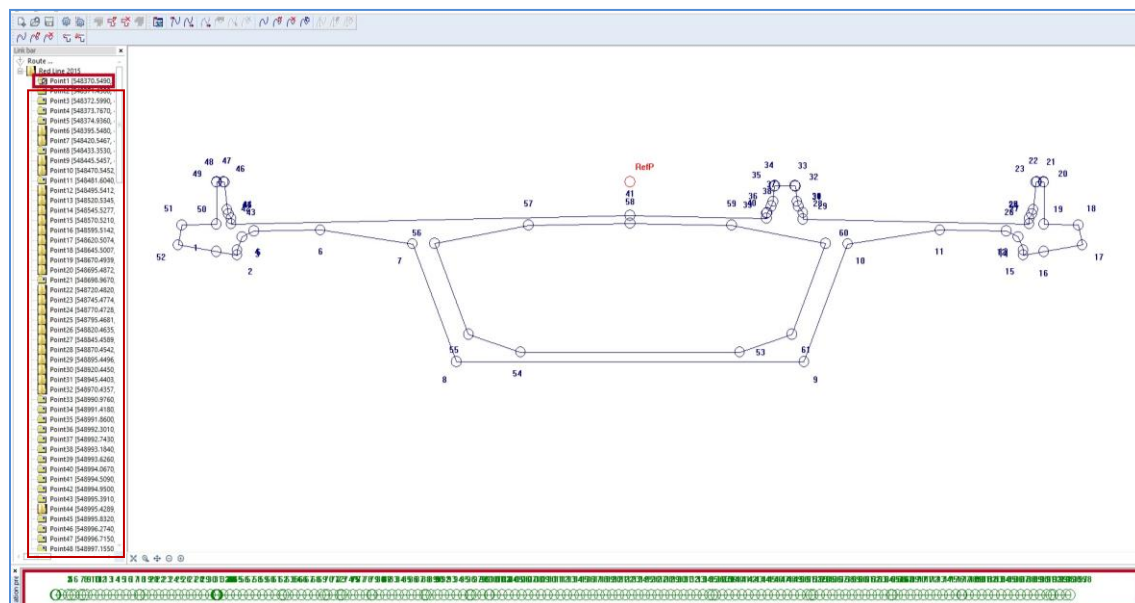
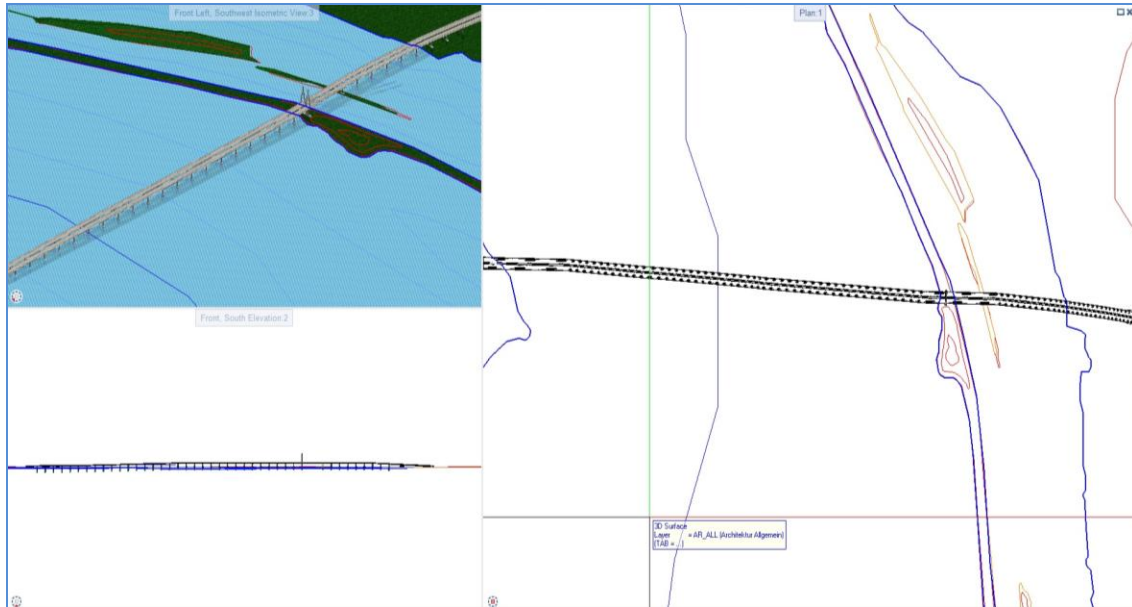


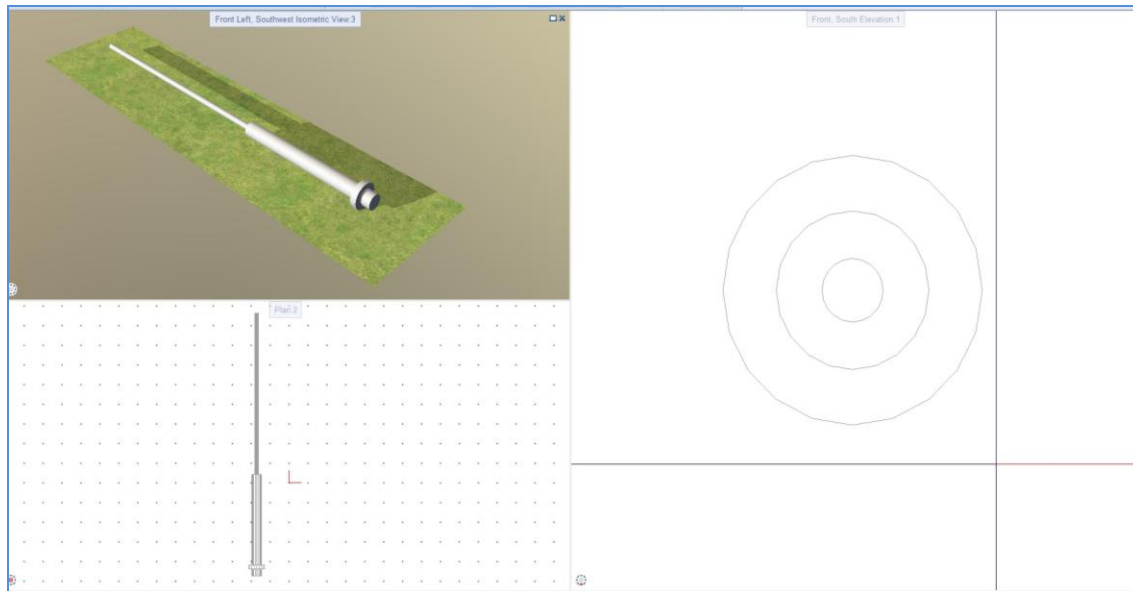
Figure 4.30: Export front view of deck to Red Line

Figure 4.31 shows the bridge deck view by using BIM after inputting the details for the 2D model and identifying the deck path "Red Line" to show the 3D model. With this, we can figure out all project details as well as detect if there are collisions that the project may face during the implementation period.



**Figure 4.31: Bridge deck view**

**Step 5:** Cables design. As shown in Figure 4.32, cable design is considered to be the most important part for bridge design because the cables have a significant impact in lifting the deck. Using BIM to design the cables requires data knowledge, which includes the base radius and the length. The cable radius and length also be established in order to obtain the 2D and 3D model. The cable length is flexible depending on the distance between the cable starting point on the deck and the tower. It is also dependent on the type of agreed materials (e.g. steel). The cable details include the radius, the length, and type of materials according to Infrastructure Canada reports. The features of this system provide an accurate analysis for cables and may be modified during the project design or implementation.



**Figure 4.32: Cable design**

**Step 6:** Project report and Adobe PDF 3D. BIM can provide reports on project details in minimal computation time (within minutes), and can be exported as a PDF, Word, or Excel document, as shown in Figure 4.33. Therefore, this technology using Allplan or any software which supports a BIM system saves time and cost, because using a traditional design to provide project reports requires a long period of time (Stewart). During these two weeks, the company could spend a lot of time and money in providing the project report.

**Parameters**

**Allplan System Parameters**

Company addr: Konrad-Zuse-Platz 1, 81829  
 Company logo: C:\ProgramData\Nemetschek AG  
 Company name: Nemetschek AG  
 Date: 11/12/2015  
 Edited by: Rida Shetwi  
 Email:  
 Project name: A New Champlain Bridge  
 Telephone Nun:  
 Time: 04:29

**User Interaction**

Note:  
 PageNo 1: 1  
 Show logo: ☒

**Overview of objects**

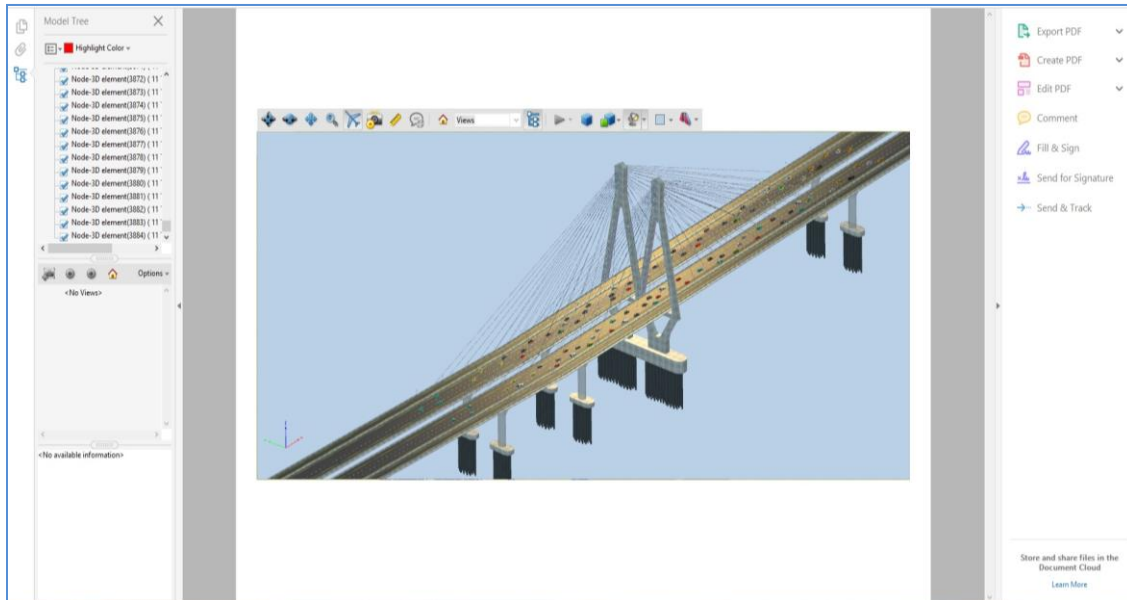
Project: A New Champlain Bridge  
 Created by: Rida Shetwi  
 Date / time: 11/12/2015 / 04:29  
 Note:

Name	Object name	Material	Quantity
	Cables	Steel	11,286.81 m
	Concrete footing	Concrete	32,969.83 m³
	Concrete footing type 2	Concreting	5,849.13 m³
	Deck	Concreting	147,034.26 m³
	Piers (Substructures)	Concrete	48,872.19 m³
Street light LAMP	Smart symbol		1,254.00 Pcs
Street light LAMP	Smart symbol	Steel structure + light bulb	1.00 Pcs
Street light LAMP	Smart symbol	Steel support structure + 1 bulb	1.00 Pcs
	Tower	Concrete	8,040.38 m³

Nemetschek AG  
 Konrad-Zuse-Platz 1, 81829 Munich / Germany

**Figure 4.33: Report generation**

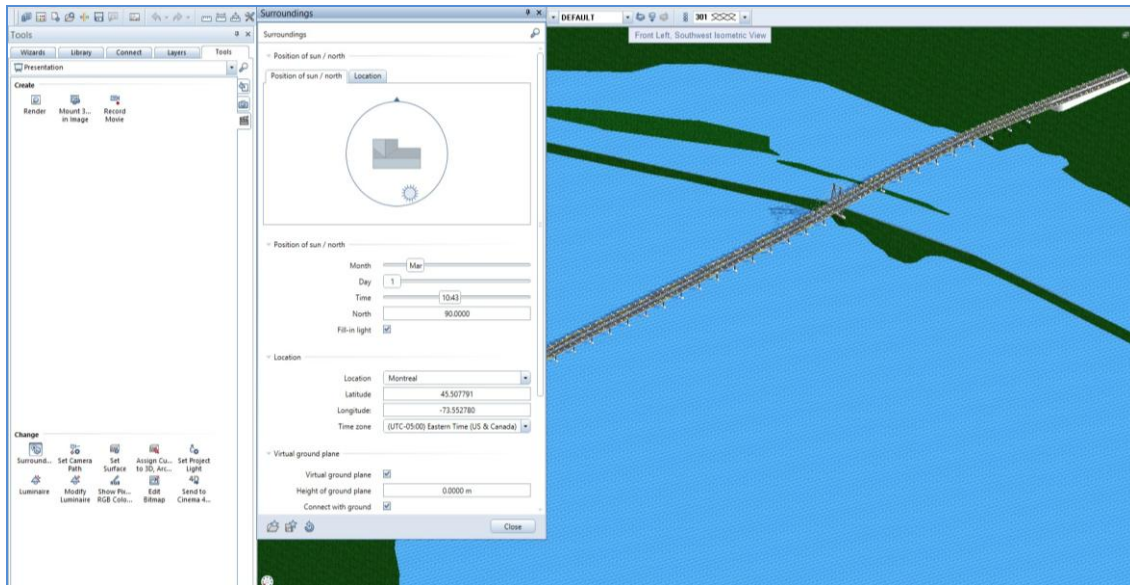
In addition, owners and contractors need to figure out all of the information about a project before realistically proceeding to the implementation stage which should be accessible to third party partners, investors, beneficiaries, contractors who require easy access to the product without special software or training. Through BIM support, the user can export parts or the entire model in Adobe PDF 3D at any time, as shown in Figure 4.34. This allows for accessibility to any third party collaboration who require no special software or training to understand the project.



**Figure 4.34: Adobe PDF 3D**

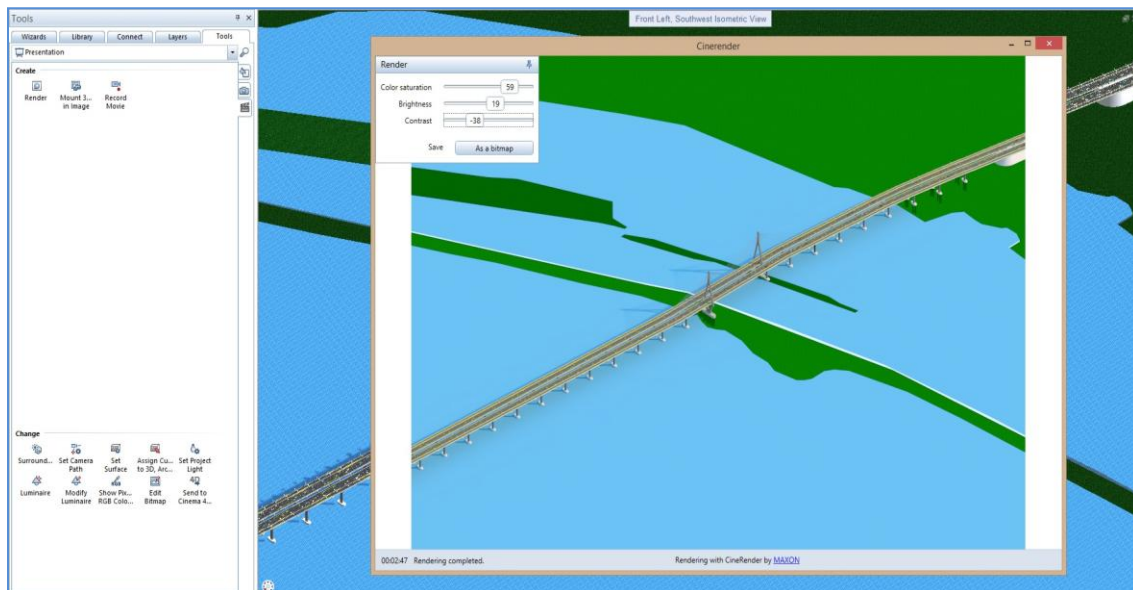
**Step 7: Project Render.** It is a process to show the project milestones. The BIM system has the ability to bring out the project details as if they were real life aesthetics. In particular, this ability depends on computer specification. The minimum BIM system requirements (computer specification) for simple models (e.g. design a small project) is a Microsoft® Windows® 7/8 64-bit operating system with a memory of 4 GB RAM. The CPU should be a *Single- or Multi-Core Intel® Pentium®, Xeon®, or i-Series processor or AMD® equivalent with SSE2 technology*, with graphics of at least 1,280 x 1,024 ([System requirements for Autodesk Revit 2016 products](#)). The operating system requirements for complex and large BIM systems are same as those for the minimum BIM system requirements, however, the system must have at least 16 GB RAM of memory. The use of a graphics requires 1,920 x 1,200, and the CPU requires a *Single- or Multi-Core Intel® Pentium®, Xeon®, or i-Series processor or AMD® equivalent with SSE2 technology* ([System requirements for Autodesk Revit 2016 products](#)).

BIM allows the user to identify the project location, such as Montreal, Canada or any other country, and the time period, such as morning or evening, etc., as shown in Figure 4.35. The process of determining the location and time are important in order to show the real project milestones, such as shadows etc.



**Figure 4.35: Rendering**

Figure 4.36 shows the final project design from the perspective of the owner, contractor, and designer, where they can see the project as in a real life scenario. As well, it allows them to figure out the problems that need to be modified before the implementation stage.



**Figure 4.36: 3D Champlain Bridge, rendered**

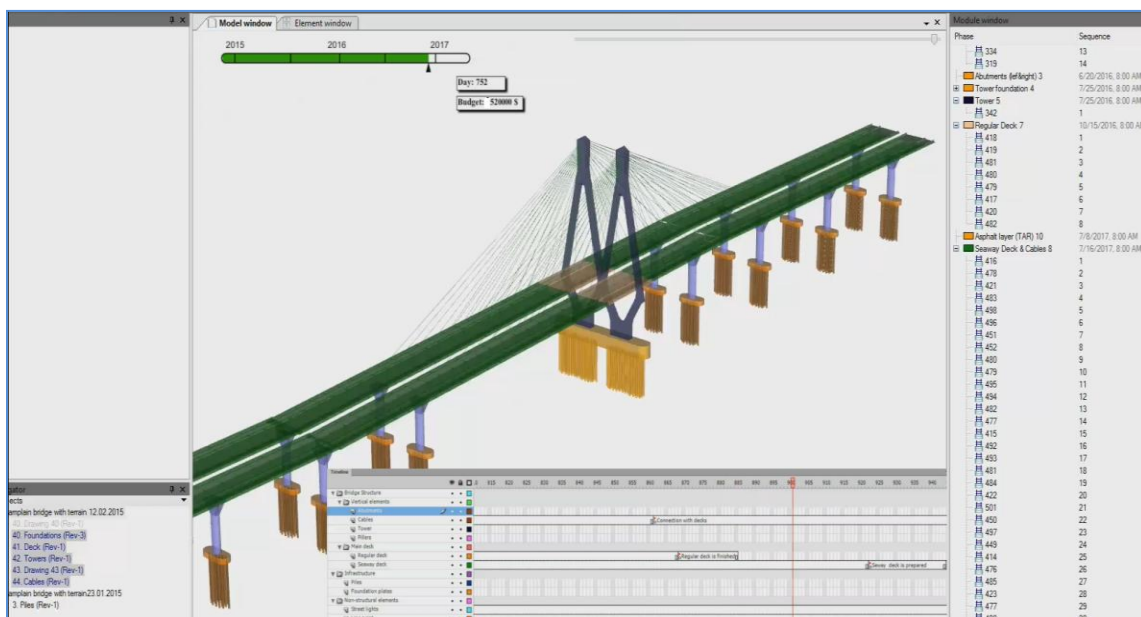


### 4.3.2 4D Modelling "Schedule & Simulation"

Based on the 3D model developed in Allplan, a 4D model was developed using TIM. This software is considered to be one of the softwares that support the 4D BIM model. We have used this software because we have obtained free support by Nemetschek Company. The 4D model can show the schedule and simulate it in the form of an animation. This model helps the involved stakeholders to figure out details related to project timing regarding the project implementation phases from the very first stages to project delivery. Moreover, the owners, engineers, and contractors can observe the project implementation from the beginning until end of the delivery using animations as shown in Figure 4.37.

The softwares that support the BIM system have the ability to provide high quality for projects. This software also allows us to check and analyze the conflicts, where the tool helps the designer figure out if there is any collision/conflicts in the project (e.g. collision of two columns). In this case the BIM can address and analyze this case, as well as prepare reports for the project including time and cost for each stage.

As previously mentioned, the 4D model is based on the 2D and 3D models, where the data is exported from 2D and 3D software to the 4D software through the IFC file. The IFC file works to export all project data, particularly quantity take-off that includes towers, Cables, and deck data etc.

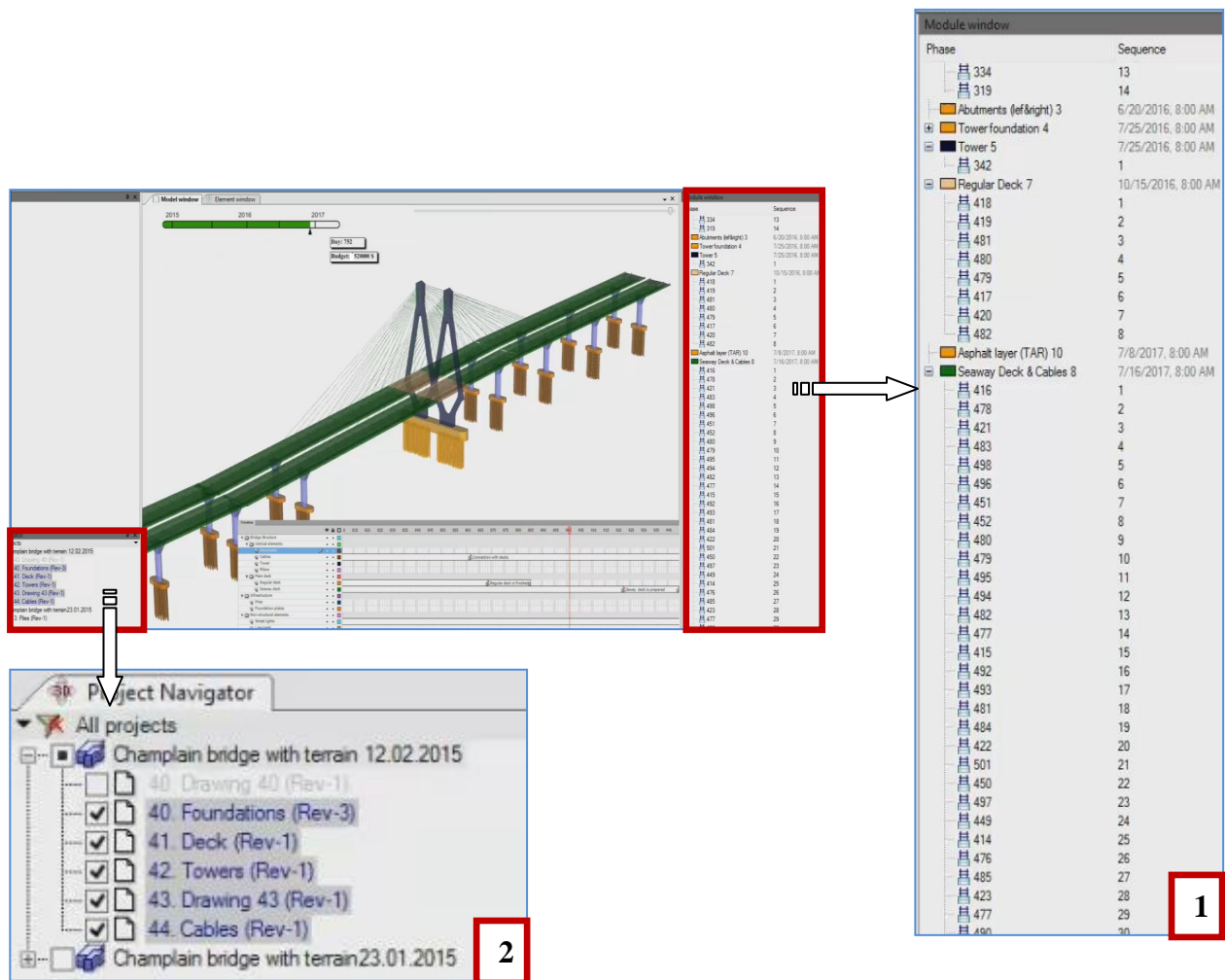


**Figure 4.37: Project schedule and simulation**

4D BIM has the ability to read all the project data that is exported from 2D and 3D BIM software, while the scheduling is done by the "designer" in accordance with the input data, which includes the project time period for each stage. This occurs because the software does not support the preparation of the automatic project schedule. In this case, we assumed the time for all project phases from the first stage to project delivery because Infrastructure Canada apologized for providing this information. Therefore, after inputting all project data such as time and cost, the software automatically provides a simulation for all project data including time and cost as shown in Figure 4.37.

In this case study, we used a 4D BIM to display the project stages with time and cost for a new Champlain Bridge as shown in Figure 4.37. The 4D BIM system depends on input data, which includes time and cost for each stage, as shown in Figure 4.37. In window 1 "Module Window", the function of this window is input data (e.g. time and costs) after importing the data from a 2D and 3D model. The features of a 4D BIM allow for easy identification of the time and different colours for each stage, which lead to easily make a distinction between the project phases. Moreover, it allows for flexibility when changing or modifying the data (e.g. time and costs) during design period.

BIM allows the designer to show and hide the project stages as shown in Figure 4.38. In window 2 "Project Navigator", this window is considered to be the control panel which shows and hides the project models, as it holds all project data (e.g. foundation, deck, cables etc).



**Figure 4.38: 4D software (module window & project navigator)**

The timeline and budget as shown in Figure 4.39, window 3, is the timeline for the project implementation phases. There is an orange line to determine the beginning and end of each stage, which helps the stakeholders to see the project phases. There are different colors in the left side of the window, such as green for the deck phase and blue for the tower etc. These colours help the designer, contractor, and owner to understand the project stages during the simulation. The timeline window appears when performing the simulation in order to show the different phases of the project along with the projected time and name of each model.

The window 4 shows the days and budget for all project phases. This window allows the owner, contractor and designer to make fast decisions about any phase; for example, if the owner wants to modify a model, the designer can do it easily since BIM system allows the user the flexibility to change or modify the project before or during the project implementation period, which leads to saving time and money.



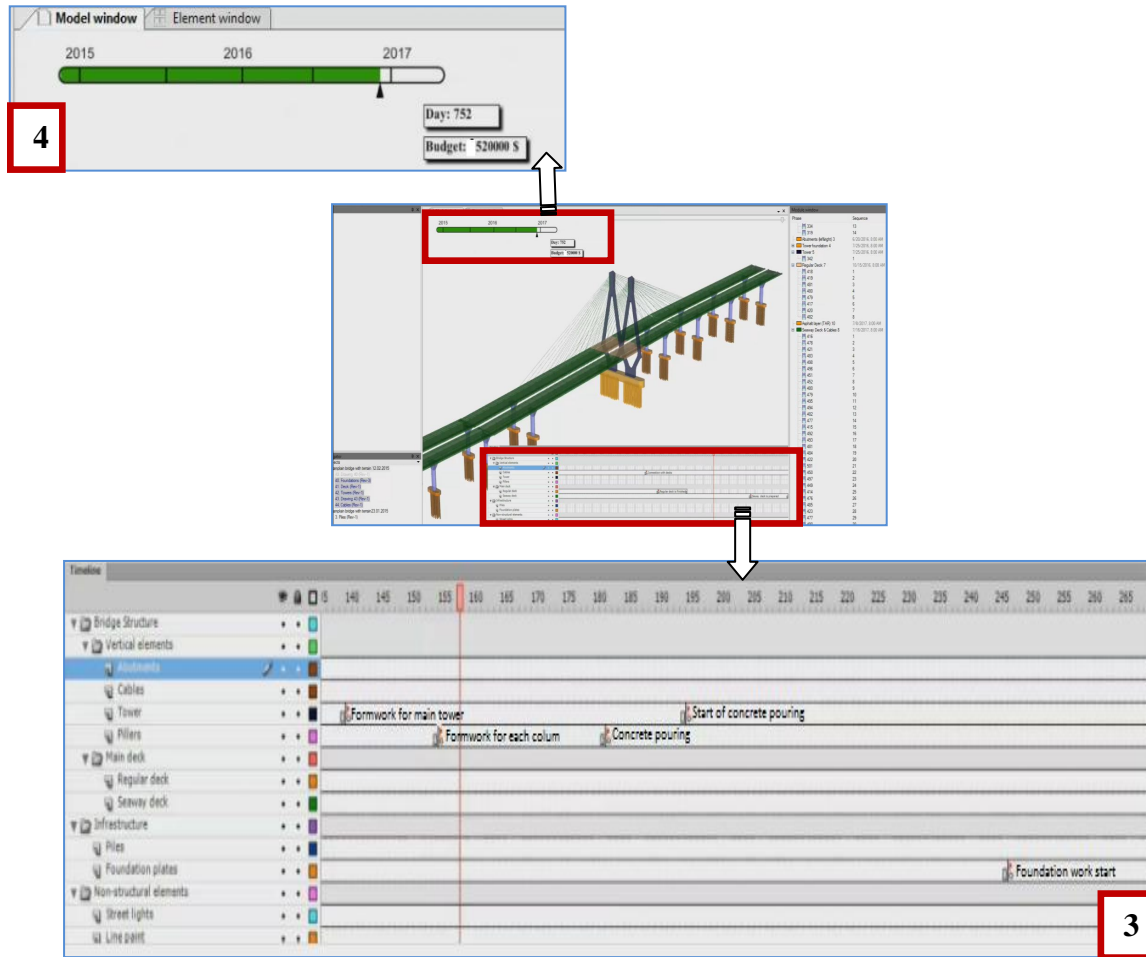


Figure 4.39: 4D software (timeline & budget)

### 4.3.3 5D Modelling " Cost Estimation"

The process of 5D modelling is performed by exporting the quantity take-off data, which includes the quantities and type of materials (from 3D modelling) through an XML or IFC file etc. In this case study, we used Nevaris software to calculate the project costs. This software is considered to be one of the software that support 5D BIM system to calculate project costs. We chose this software, because we obtained the support (free training and download 5D software) from Nemetschek Company.

The 5D BIM system works to calculate the project costs according to the data, which was imported from 3D BIM. For example, the software calculates the cost of reinforced mesh, steel cables, work form, etc. The unit prices are automatically calculated and updated for the project according to the state markets. These prices are then updated from the software company office

that support the BIM system. The 5D model also has the ability to modify the project prices during the project design and implementation period and convert the currency from Euro to CAD etc. It also presents the project as a spreadsheet or PDF file.

In this case study we faced a problem regarding prices. The prices that we used in the traditional system calculated the project cost according to the Canadian markets in 2008, as other recent sources were unavailable. Moreover, the prices that we have used in BIM were set according to the German and Austrian markets because the unit price that support the Nevaris software depends on the German and Austrian markets. This software does not support Canadian markets and other states markets. These prices are updated from the Nemetschek company office because this company support the 5D BIM system.

Figure 4.40 shows the table of cost estimation for a New Champlain Bridge project by using 5D BIM system, where the table is divided into around 8 columns. This system provides the reference number as a way to provide a link between the table of costs and the project details, where this code helps the designer, contractor, or owner figure out all the project details, as shown in Figure 4.41. For example, the code (02.02.480) in the first column of Figure 49, is also under the item number in Figure 4.41. The code specifically refers to reinforced mesh and provides the accounts in details, quantities, and the unit for each column. Moreover, the BIM system allows the designer to export the details in an Excel or XPS file.

Bill of quantities: 2015 - DEMO Bill of Quantities				New Champlain Bridge Scenario 1						Search
Reference number	Codetext	Type	Short text	Quantity	Unit	Unit price	Amount	C. DIN276:1981	Gewerkegliederung...	DIN276-1:2008-12
<b>BoQ DEMO Bill of Quantities</b>							<b>506,026,235.85</b>			
<b>02</b>	<b>02</b>	<b>T1</b>	<b>SUBSTRUCTURE</b>				<b>79,974,860.19</b>			
<b>02.02</b>	<b>013</b>	<b>T2</b>	<b>CONCRETE AND REINFORCED CONCR...</b>				<b>79,974,860.19</b>			
02.02.480	013_014	I	mesh reinforcement	27,667,019.109	kg	1.175	32,508,747.45		013 Betonarbeiten	300 Bauwerk - Baukonstruktionen
02.02.490	013_015	I	Betonstabstahl (f. Kostenberechnung)	10,247,044.091	kg	1.175	12,040,276.81		013 Betonarbeiten	300 Bauwerk - Baukonstruktionen
02.02.510	013_017	I	form work	2,512,470.633	m2	14.100	35,425,835.93		013 Betonarbeiten	330 Außenwände
<b>06</b>	<b>06</b>	<b>T1</b>	<b>BRIDGE PARTS</b>				<b>426,051,375.66</b>			
<b>06.1</b>	<b>061</b>	<b>T2</b>	<b>concrete parts</b>				<b>421,409,677.51</b>			
06.1.10	013_020	I	reinforced concrete bridge pier	1,024,704.383	m3	411.250	421,409,677.51		013 Betonarbeiten	331 Tragende Außenwände
<b>06.2</b>	<b>062</b>	<b>T2</b>	<b>steel cable</b>				<b>4,641,698.15</b>			
06.2.10	100_001	I	steel cable	11,286.804	m	411.250	4,641,698.15		017 Stahlbauarbeiten	370 Baukonstruktive Einbauten

**Figure 4.40: 5D cost estimation**

BIM can also provide the short text, which includes the project items such as steel cable, form work, and reinforced concrete bridge pier etc. The 5D BIM system calculates the project cost according to these items, and through these elements, the designer, owner and contractor can figure out the table of project cost details.

Also BIM can provide other details such as quantity and unit, where the total project quantity helps the stakeholders to determine and all quantities as well as the unit for each quantity.

Identifying the unit price for each item in BIM system is according to the local markets and companies, which are supported by the softwares of BIM system (e.g. Nevaris software the unit price according to German and Austrian markets and update by Nemetschek company). This system is flexible in modifying the quantities and unit prices, which leads to reduce the time and cost of project.

Moreover, the 5D BIM system can automatically calculate the total amount for each item, and the total amount for the project. The BIM system has the ability to update the changes, which include the total amount per item and the total amount for the project.

Item number	Short text / beginning	Quantity	Variable	Unit	Type	Name
614.157	614.157/(0.538*2*PI)*171.000/360*25.000+0.538*2*PI* *126.000/360*25.000+0.5*(0.247*0.485)*25.000+0.5*(0.085+0.247) *0.053*25.000+0.5*(0.247+0.385)*0.100*25.000+0.5*(0.485+0.385) *0.138*25.000*27*(1)	614.157				Column 0016Col
02.02.480	mesh reinforcement	614.157		kg		
614.157	614.157/(0.538*2*PI)*135.000/360*25.000+0.538*2*PI* *162.000/360*25.000+0.5*(0.247*0.485)*25.000+0.5*(0.085+0.247) *0.053*25.000+0.5*(0.247+0.385)*0.100*25.000+0.5*(0.485+0.385) *0.138*25.000*27*(1)	614.157				Column 0016Col
02.02.480	mesh reinforcement	614.412		kg		
614.412	614.412/(0.538*2*PI)*279.000/360*25.000+0.5*(0.085*0.538)*25.000+0.5*(0.085+0.247)*0.053*25.000+0.5*(0.247+0.385)*0.100*25.000+0.5*(0.385+0.485)*0.138*25.000+0.5*(0.538+0.485)*0.162*25.000*27*(1)	614.412				Column 0016Col
02.02.480	mesh reinforcement	614.412		kg		
614.412	614.412/(0.538*2*PI)*279.000/360*25.000+0.5*(0.085*0.538)*25.000+0.5*(0.085+0.247)*0.053*25.000+0.5*(0.247+0.385)*0.100*25.000+0.5*(0.385+0.485)*0.138*25.000+0.5*(0.538+0.485)*0.162*25.000*27*(1)	614.412				Column 0016Col
02.02.480	mesh reinforcement	614.412		kg		
614.412	614.412/(0.538*2*PI)*279.000/360*25.000+0.5*(0.085*0.538)*25.000+0.5*(0.085+0.247)*0.053*25.000+0.5*(0.247+0.385)*0.100*25.000+0.5*(0.385+0.485)*0.138*25.000+0.5*(0.538+0.485)*0.162*25.000*27*(1)	614.412				Column 0016Col
02.02.480	mesh reinforcement	614.412		kg		
614.412	614.412/(0.538*2*PI)*279.000/360*25.000+0.5*(0.085*0.538)*25.000+0.5*(0.085+0.247)*0.053*25.000+0.5*(0.247+0.385)*0.100*25.000+0.5*(0.385+0.485)*0.138*25.000+0.5*(0.538+0.485)*0.162*25.000*27*(1)	614.412				Column 0016Col
02.02.480	mesh reinforcement	614.412		kg		
614.412	614.412/(0.538*2*PI)*279.000/360*25.000+0.5*(0.085*0.538)*25.000+0.5*(0.085+0.247)*0.053*25.000+0.5*(0.247+0.385)*0.100*25.000+0.5*(0.385+0.485)*0.138*25.000+0.5*(0.538+0.485)*0.162*25.000*27*(1)	614.412				Column 0016Col
02.02.480	mesh reinforcement	614.412		kg		
614.412	614.412/(0.538*2*PI)*279.000/360*25.000+0.5*(0.085*0.538)*25.000+0.5*(0.085+0.247)*0.053*25.000+0.5*(0.247+0.385)*0.100*25.000+0.5*(0.385+0.485)*0.138*25.000+0.5*(0.538+0.485)*0.162*25.000*27*(1)	614.412				Column 0016Col
02.02.480	mesh reinforcement	614.794		kg		
614.794	614.794/(0.538*2*PI)*171.000/360*25.000+0.538*2*PI* *135.000/360*25.000+0.5*(0.385+0.385)*25.000+2*(0.5*(0.085+0.247) *0.053*25.000+0.5*(0.385+0.247)*0.100*25.000+0.5*(0.247*0.485)*25.000 +0.5*(0.247+0.385)*0.100*25.000+0.5*(0.485+0.385)*0.138*25.000*27*(1)	614.794				Column 0016Col
02.02.480	mesh reinforcement	614.794		kg		
614.794	614.794/(0.538*2*PI)*171.000/360*25.000+0.538*2*PI* *135.000/360*25.000+0.5*(0.385+0.385)*25.000+2*(0.5*(0.085+0.247) *0.053*25.000+0.5*(0.385+0.247)*0.100*25.000+0.5*(0.247*0.485)*25.000 +0.5*(0.247+0.385)*0.100*25.000+0.5*(0.485+0.385)*0.138*25.000*27*(1)	614.794				Column 0016Col

Figure 4.41: Project details (quantities)

## **CHAPTER 5 DETAILED ANALYSIS OF RESULTS**

### **5.1 3D Visualization**

3D visualization is an important feature and it can be used to integrate all project information in one model based on BIM systems, as shown in the Figures below (scenario 1 and 2). The differences between both scenarios are tower location, while the other categories remain the same, including the columns, the deck, the number of street light columns, etc.

However, aesthetically, scenario 2 was considered superior to scenario 1, because scenario 2 shows the towers and cables in different locations, whereas scenario 1 shows the towers and cables in one location. Therefore, in our view, the separation of the towers allows the cables to overlap in the middle of the seaway, and the emergence of cables in the middle of the bridge forms the letter (M). This creates a more distinct visual identity, which gives the bridge a more distinct design than in scenario 1.

By using the Allplan software, which supports the BIM system, we have reached several points that were missing in the traditional design. These points are very important, whether at the current time or in the future. Amongst these points is a full knowledge of the project elements before its implementation. Due to the flexibility of the system, we have determined the type of materials, as this model is flexible and easy to change, including modifying materials and design without any constraints.

As an example in a real life scenario, using the traditional system to design and implement the project requires time for project design completion because this system does not integrate all information in one model. For example, a 2D project design needs to input the length and width while the height is inputted after the completion of all the 2D project details in order to present the 3D model. However, by using the BIM system, inputting the length and width, height and type of materials can be done simultaneously, because this system integrates all information in one model.

If the project faces problems during the implementation period (e.g. Change or modify the design), using a BIM system does allows for quick change or modification of the design. This is because the BIM system can easily change or modify the design in a short period of time. For example, changing the column width on a 2D model automatically changes this data in a 3D model or in any other panel related to this column (e.g. sectors, etc), while by using the

traditional system, the design is modified one by one, as this does not integrate the change from a 2D to 3D model at the same time, which may lead to spending a long time in modifying the design. So, in this case the BIM system leads to a reduction in time and cost and presents the project in real life.

As mentioned earlier, we have used Google Earth/SketchUp to import the terrain points. We determined the terrain points for the Champlain Bridge location which are considered to be the foundation for the project design, such as determining the site of abutments, columns etc.

### Scenario 1

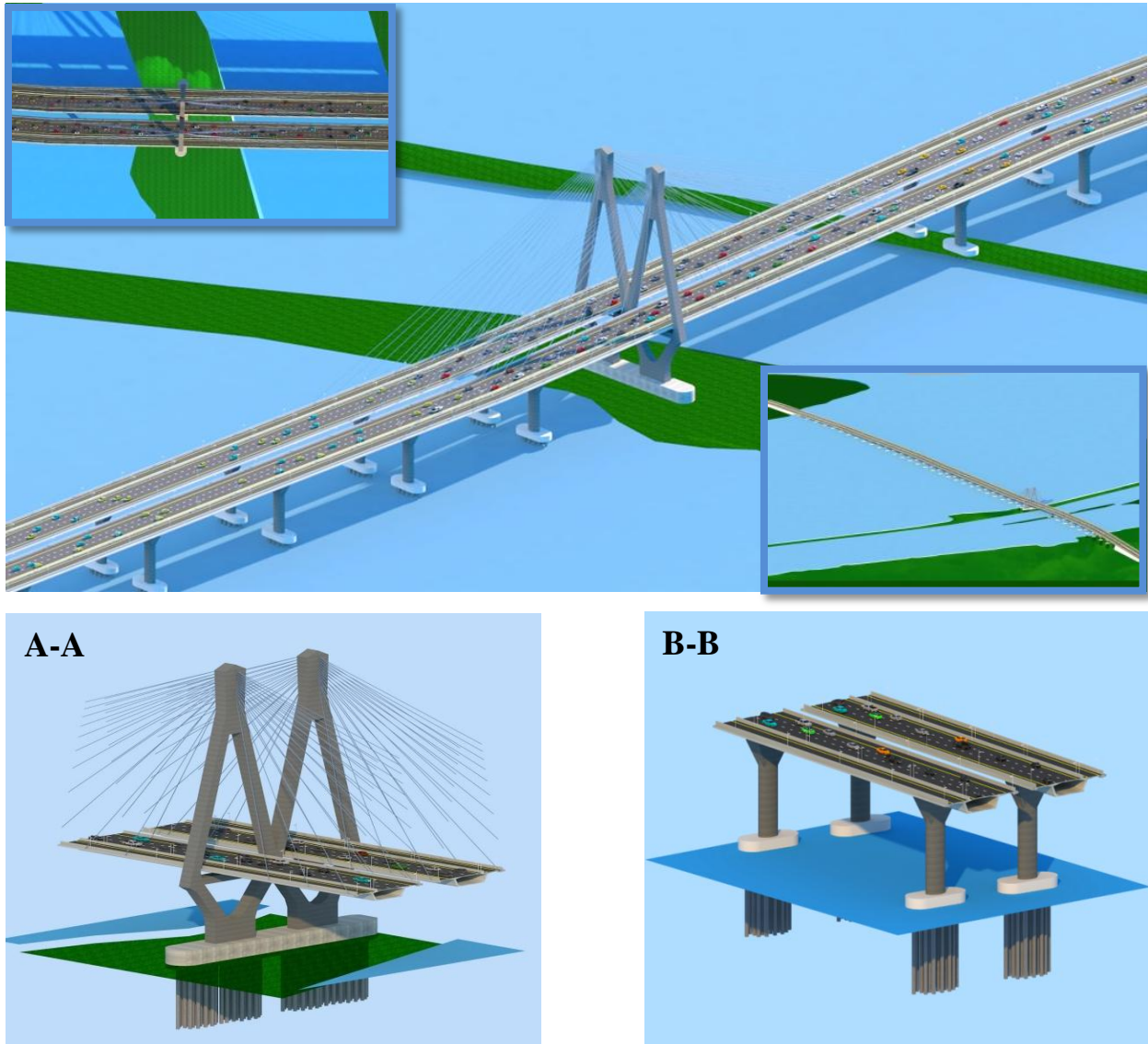


Figure 5.1: 3D visualization for scenario 1



As shown in scenarios 1 and 2, there are several views for a New Champlain Bridge, such as the top view and 3D view; moreover, there are two sectors in the middle, A-A and B-B. Through these views, we can forecast the project before its implementation, and the designer and owner can change or modify the design accordingly. This leads to reductions in cost, time delivery, and reduces problems which the project could face during the implementation period.

## Scenario 2

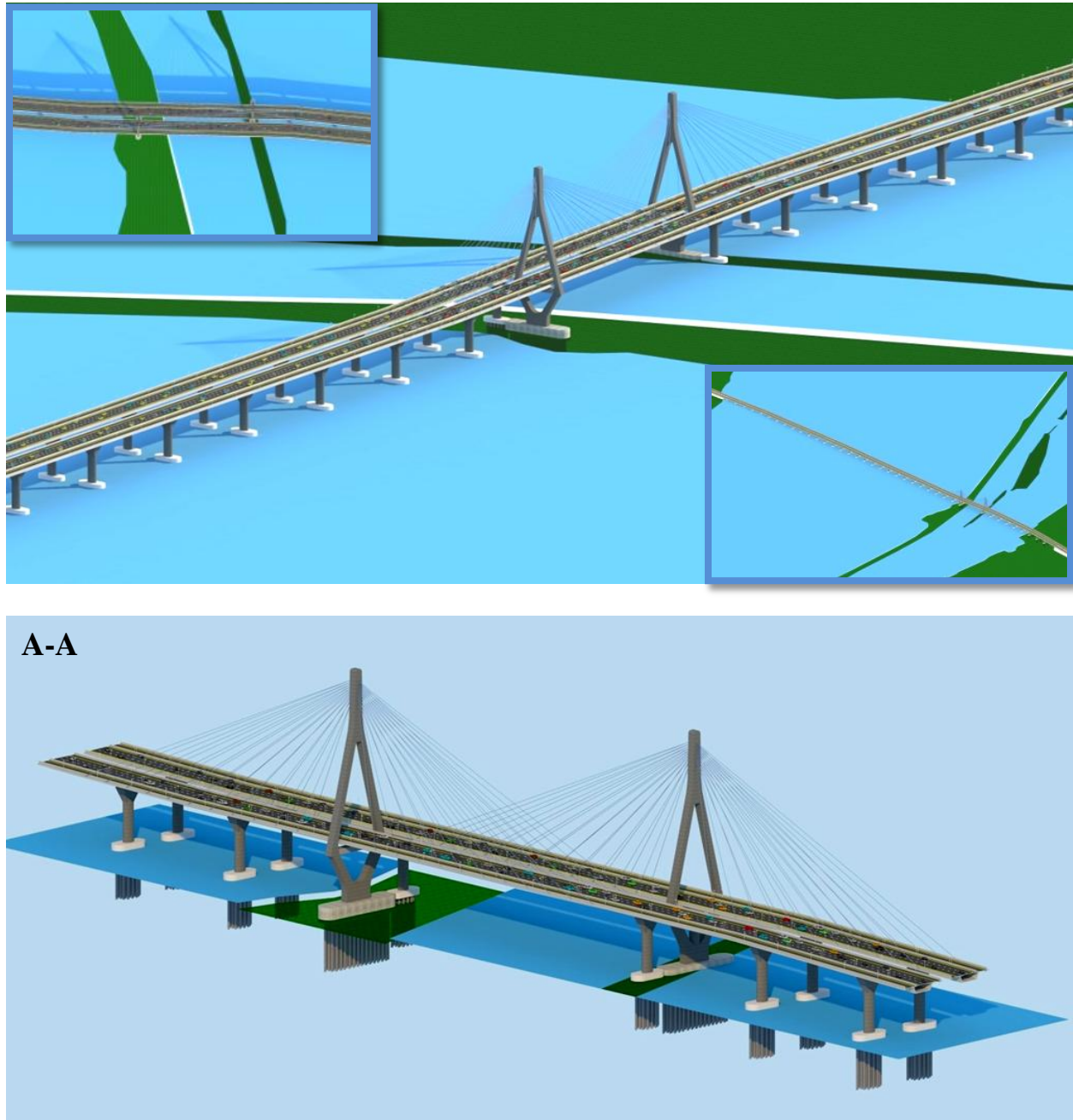
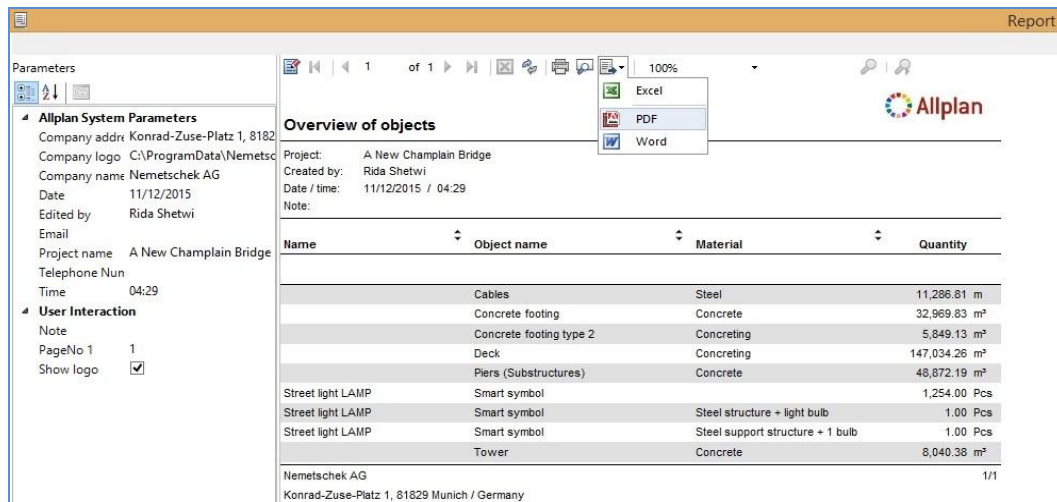


Figure 5.2: 3D visualization for scenario 2

After completing the design of all structural items including deck, cables, abutments, columns etc by using BIM system, BIM can present all these details as a PDF, Word or Excel file. These details include quantities and materials for each model, as shown in Figure 5.3. All of this information was gathered in a few hours, whereas using a traditional system would require at least one week to provide all project information, and it may be inaccurate.



**Parameters**

**Allplan System Parameters**  
 Company addr: Konrad-Zuse-Platz 1, 8182  
 Company logo: C:\ProgramData\Nemetsc  
 Company name: Nemetschek AG  
 Date: 11/12/2015  
 Edited by: Rida Shetwi  
 Email:  
 Project name: A New Champlain Bridge  
 Telephone Nun:  
 Time: 04:29

**User Interaction**  
 Note:  
 PageNo 1: 1  
 Show logo: ☒

**Overview of objects**

Project: A New Champlain Bridge  
 Created by: Rida Shetwi  
 Date / time: 11/12/2015 / 04:29  
 Note:

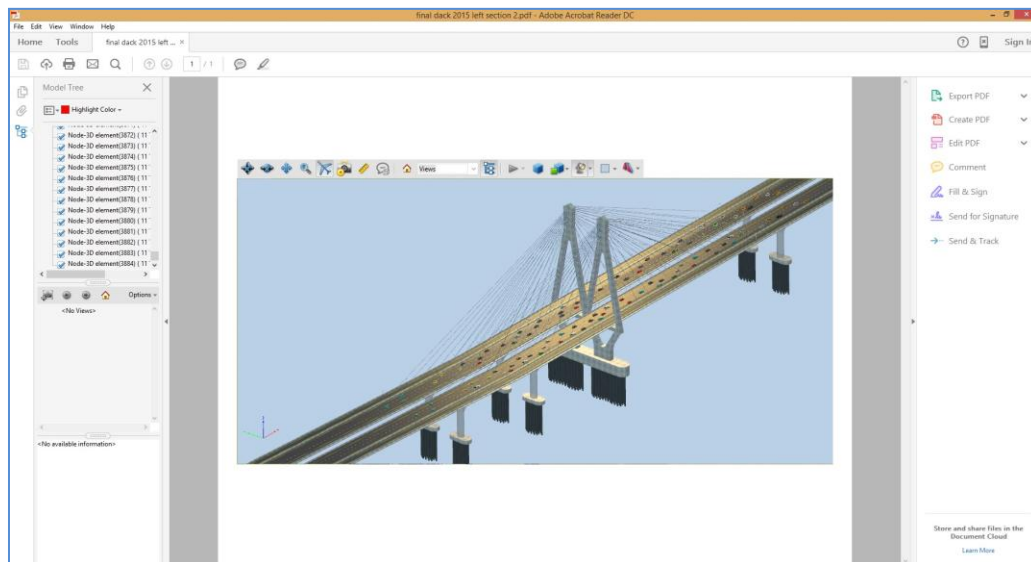
Name	Object name	Material	Quantity
	Cables	Steel	11,286.81 m
	Concrete footing	Concrete	32,969.83 m³
	Concrete footing type 2	Concreting	5,849.13 m³
	Deck	Concreting	147,034.26 m³
	Piers (Substructures)	Concrete	48,872.19 m³
Street light LAMP	Smart symbol		1,254.00 Pcs
Street light LAMP	Smart symbol	Steel structure + light bulb	1.00 Pcs
Street light LAMP	Smart symbol	Steel support structure + 1 bulb	1.00 Pcs
	Tower	Concrete	8,040.38 m³

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 Konrad-Zuse-Platz 1, 81829 Munich / Germany

1/1

**Figure 5.3: Report "overview of objects"**

Moreover, the BIM "Allplan" software also provides the 3D project model in a PDF file, so with this technology, the owner and contractor will not need any of the specific knowledge or experience which is required to use the software. By using a PDF file as shown in Figure 5.4, the owner and contractor could figure out all project designs without resorting to using software.



**Figure 5.4: Adobe PDF 3D**

## 5.2 4D Schedule

### Scenario 1 and Scenario 2

As mentioned earlier on page 66, the time calculation of the project using the traditional method through manual calculation is considered to be the same calculation as using the BIM system.

Table 5.1 and Figure 5.5 shows the traditional scheduling of the project using a spreadsheet. As we can see, the timing in the table only illustrates the start and finish. These details are not enough for an appropriate life cycle analysis, specifically for stakeholders e.g. owners and contractors. It is difficult to predict or figure out the problems that the project may face during the implementation period, such as the collision, the electric lines and sewage issues etc., because this system does not support a simulation to see the project in real life, as does the BIM system. Therefore, the project would face several risks and problems that may lead to an increase in cost and change time project delivery.

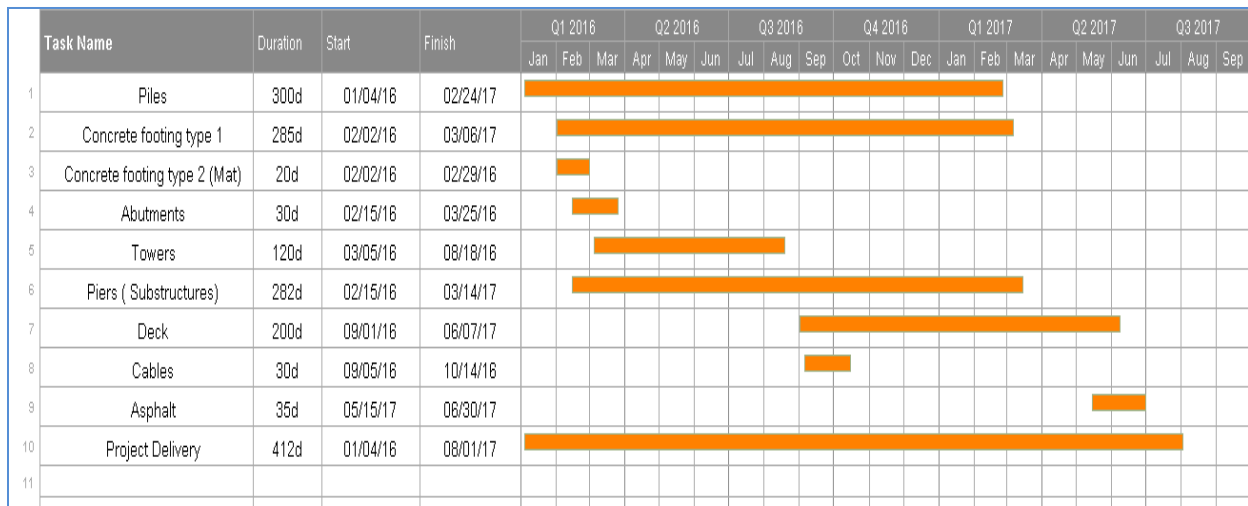
**Table 5.1: Schedule for scenario 1&2**

Task Name	Schedule		
	Duration	Start	Finish
Piles	300	01-04-16	02-24-17
Concrete footing type 1	285	02-02-16	03-06-17
Concrete footing type 2 (Mat)	20	02-02-16	02-29-16
Abutments	30	02-15-16	03-25-16
Towers	120	03-05-16	08-18-16
Piers (Substructures)	282	02-15-16	03-14-17
Deck	200	09-01-16	06-07-17
Cables	30	09-05-16	10-14-16
Asphalt	35	05-15-17	06-30-17
Project Delivery	412	01-04-2016	08-01-17

Table 5.1 shows the project schedule. We have around 9 stages, where each stage has a different implementation period ranging from 20 to 300 days. The most complex stage for the project is the foundation, such as piles, concrete footing, piers (substructures). We noted that the piles take a long time to construct (around 300 days), because this complex stage takes place under water and is considered the foundation for the entire project. Then the concrete footing and piers (substructures) take around 285 days, and are also considered the foundation for the entire

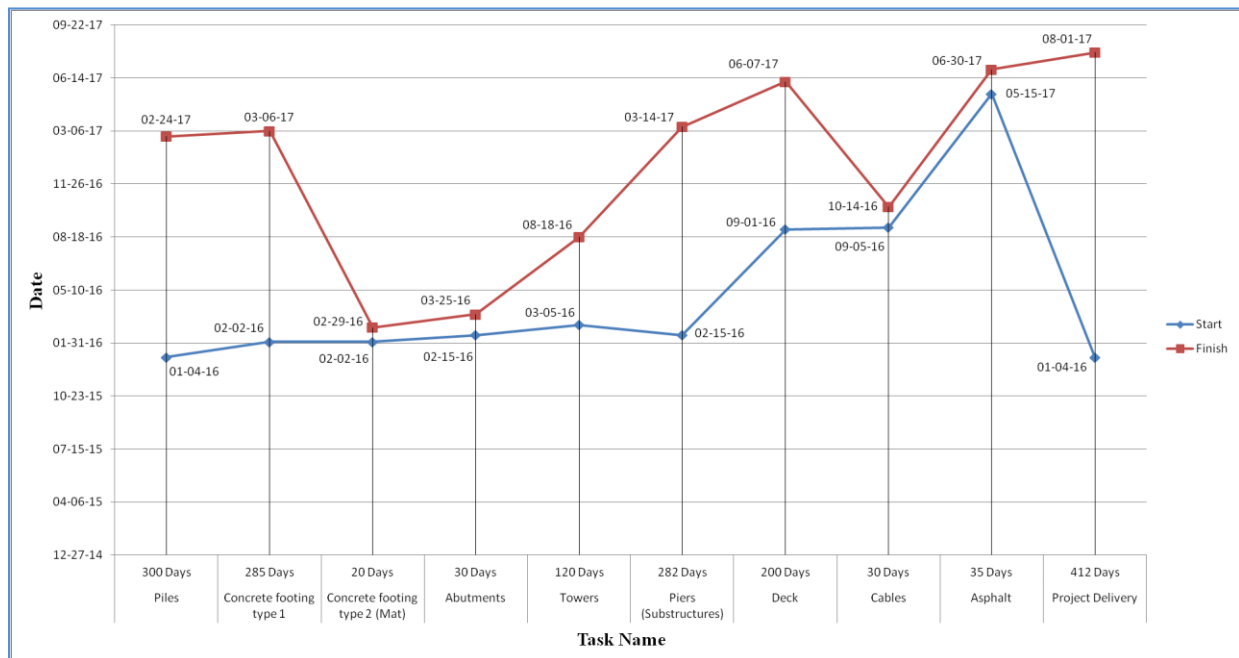


project, while the other stages require fewer days, because these stages, such as towers, cables and deck etc, take place over the foundations.



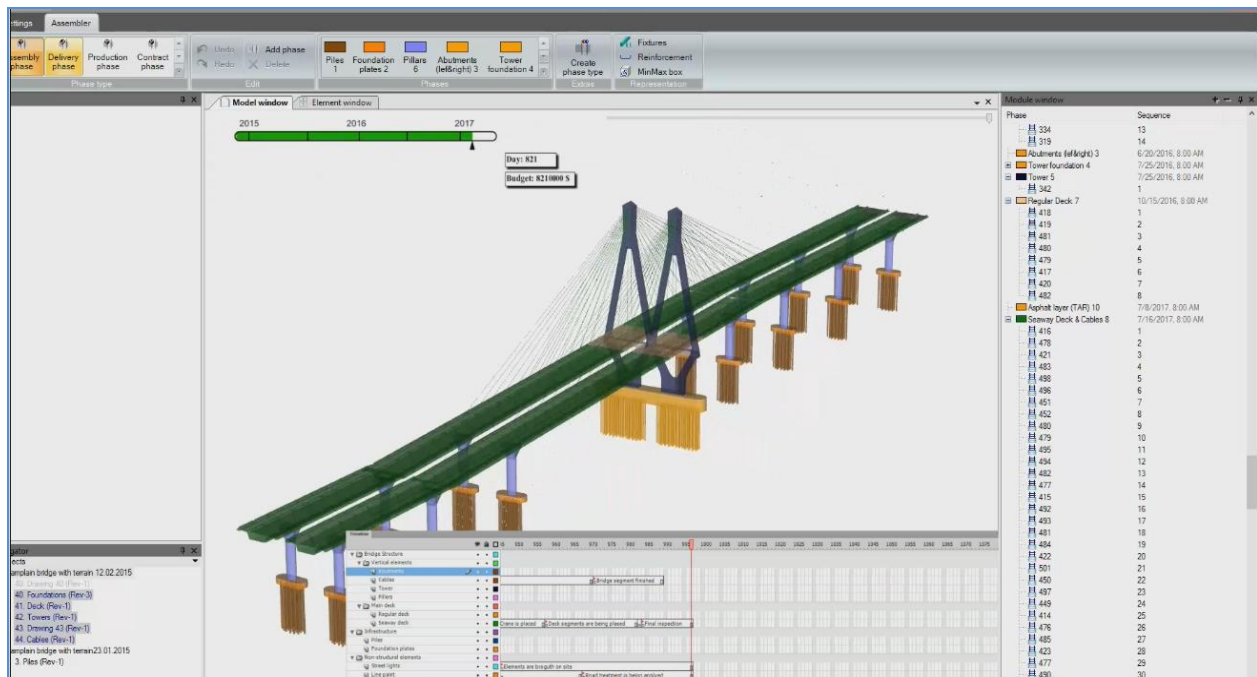
**Figure 5.5: Schedule and timeline for scenario 1&2 by using traditional system**

Figure 5.6 shows more clarification for the timing of project phases when using a traditional method, where this figure illustrates the start and finish of each stage. As noted, there are two colors- blue and red, which express the beginning and end of each stage. This Figure helps the owner and contractor to figure out the implementation time for each stage but can't predict the events or problems that may face the project during the implementation period.



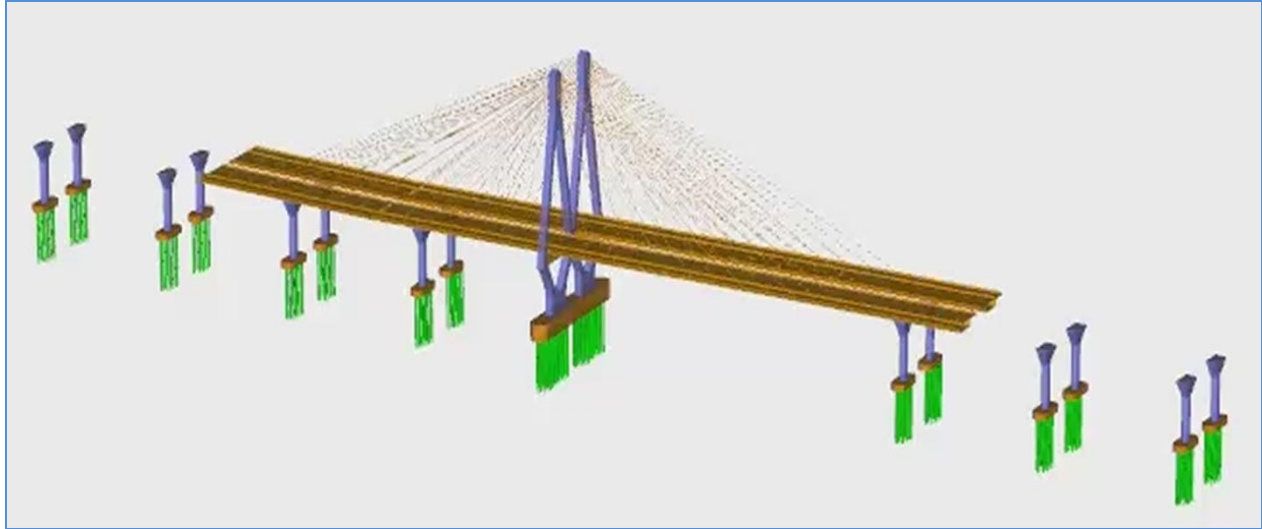
**Figure 5.6: Comparison of the time among all stages by using traditional system**

Figure 5.7 shows the new technology of the BIM system by using TIM software. This gives us access to more detailed project information, such as the life cycle, collision, time and the cost estimation evolution as the timeline progresses by using the simulation. Moreover, it is easy to change the project time period here. Therefore, in this project, we were able to find out all project conflicts, such as cables and piles before project implementation, which lead to a reduction in the time and cost. It also allowed for project delivery at a fixed time. Furthermore, we were able to simulate all project stages in real life. To view the simulation, [Click here](#)



**Figure 5.7: 4D modelling by using BIM (TIM software)**

Moreover, Figure 5.9 shows the module window. Through this window, we were able to put in the project schedule data for all stages. The software then gave us the project results, which were time period and costs for all project phases, as shown in Figures 5.8 and 5.10. Therefore, through this simulation, we ensured that the project will be implemented without facing any foreseeable problems during the implementation period, which means that, in this case, the cost and time for project delivery will be fixed or minimal changes.



**Figure 5.8: BIM project simulation (TIM Software)**

As an example to illustrate the process of using the traditional and BIM system to implement the projects. Let us assume that the project faces a problem where there is a danger of collision between power line and column during the implementation process. The contractor in this case is not responsible for these problems, because they happened due to an oversight during the design. Because of this system, the "traditional method" does not support the simulation to predict the problems that the project may face during implementation. These obstacles lead to an increase in the time and cost, and sometimes they are difficult to address during the implement period.

The BIM "4D modelling" system has the ability to analyze and address the "collision" problem during the design period. As mentioned earlier, if there is a collision between the power line and column, the "4D BIM" system has the ability to show the designers related to this problem during the design by simulation. In this case, the designer can address this problem without any increase in the time and cost. Moreover, the simulation allows for the owner and contractor to see all details of the project stages in a real life scenario, so the BIM system has the ability to deliver the project at the agreed-upon time.

Module window	
Phase	Sequence
334	13
319	14
Abutments (left&right) 3	6/20/2016, 8:00 AM
Tower foundation 4	7/25/2016, 8:00 AM
Tower 5	7/25/2016, 8:00 AM
342	1
Regular Deck 7	10/15/2016, 8:00 AM
418	1
419	2
481	3
480	4
479	5
417	6
420	7
482	8
Asphalt layer (TAR) 10	7/8/2017, 8:00 AM
Seaway Deck & Cables 8	7/16/2017, 8:00 AM
416	1
478	2
421	3
483	4
498	5
496	6
451	7
452	8
480	9
479	10
495	11
494	12
482	13
477	14
415	15
492	16
493	17
481	18
484	19
422	20
501	21
450	22
497	23
449	24
414	25
476	26
485	27
423	28
477	29
490	30

Figure 5.9: BIM module window (TIM software)

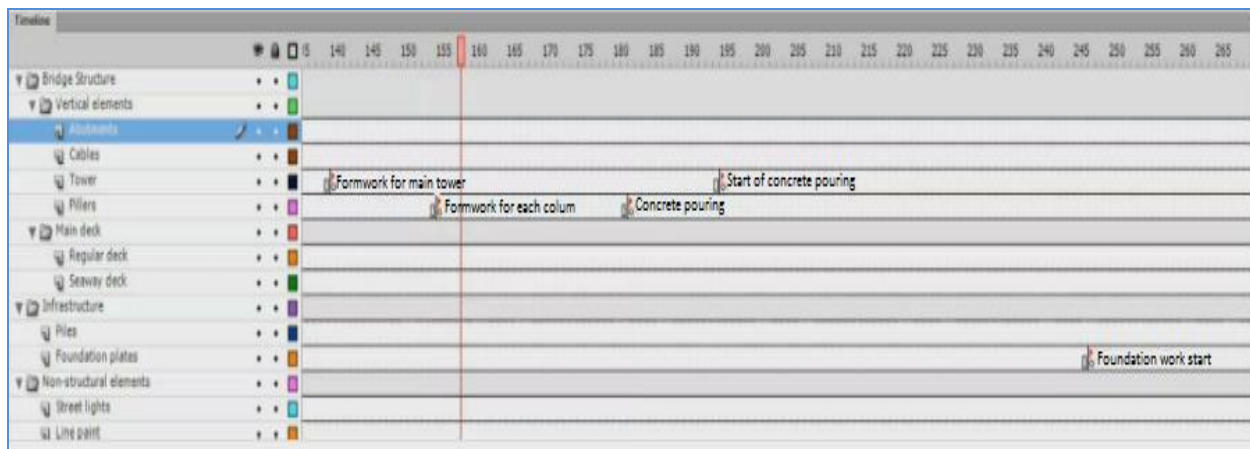
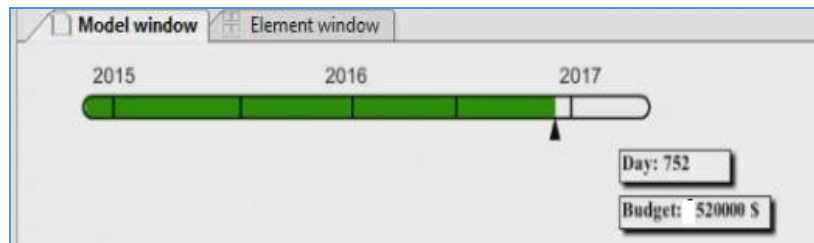


Figure 5.10: BIM time and cost project (TIM software)

## 5.3 5D Cost Estimation

The project consists of several phases ranging from pile installation all the way until asphalt installation. Here, we calculated the project cost estimation by using the traditional method and the BIM system for two scenarios. The estimate does not include the labour cost, however, due to the difficulty we experienced in obtaining data that contributed to the labour cost estimation.

### 5.3.1 Cost Estimation by Using Traditional Method

Using the traditional method to calculate the project costs requires calculating the project quantities manually for each unit such as columns, piles and cables etc. This means these calculations take time to complete, whereas using the computer scripts for these calculations could take less time. These calculations, however, may be inaccurate. When using the traditional method, the cost for each model as shown below in scenario 1 and 2 requires a long time to complete. This system does not require knowledge of software, but it rather requires experience in order to determine the cost and quantity for each item. Examples include figuring out the cost of cement or iron the markets as well as determining how to calculate the quantities. In addition, a disadvantage of this system is that the cost updates need to follow the market prices manually every time because this system does not integrate all tools into one model as in the BIM system. This means that the traditional system may give inaccurate results for the project, which is why most of the projects built using the traditional system usually face problems during the implementation stage, which ultimately increase the project cost.

#### Scenario 1

The data that we used in this project to calculate the project cost was collected according to Canadian markets in 2008. We changed the prices accordingly to predict the 2015 Canadian market by using the Consumer Price Index (CPI) according to Bank of Canada ([Inflation Calculator](#)). We used these prices because we lacked the price details that were used for a New Champlain Bridge. However, these prices were more realistic because they were identical to the Canadian markets.

Cost estimation going through several phases starting from piles until asphalt. At this point, we have used sample calculations for all phases as follow:

### Sample Calculations For Piles

The unit quantity of piles is  $m^3$  and the unit cost is CAN \$588.6 according to the Canadian market, so the total value for driver piles is  $32,833.52 m^3$  ([Conceptual Engineering Report Final 080211](#)) and

$$32,833.52 \times 588.6 = \text{CAN } \$19,325,809.87$$

### Sample Calculations For Concrete Footing Type 1

The unit quantity of concrete footing type 1 is  $m^3$  and the unit cost is CAN \$588.6 according to the Canadian market.

The total value for concrete footing type 1 is therefore  $23,557.396 m^3$  ([Conceptual Engineering Report Final 080211](#)) and

$$23,557.396 \times 588.6 = \text{CAN } \$13,865,883.29$$

### Sample Calculations For Concrete Footing Type 2 (Mat)

The unit cost of concrete footing type 1 is CAN \$588.6 and the unit quantity is  $m^3$  according to the Canadian market, yielding a total value of  $1,586.414 m^3$  ([Conceptual Engineering Report Final 080211](#)) and

$$1,586.414 \times 588.6 = \text{CAN } \$933,763.28 \text{ for concrete footing type 2.}$$

### Sample Calculations For Abutments

The unit quantity is  $m^3$

The unit cost is CAN \$588.6 ([Conceptual Engineering Report Final 080211](#))

The total value for concrete footing type 2 is  $2,213.2 m^3$  and

$$2,213.2 \times 588.6 = \text{CAN } \$1,302,689.52$$

### Sample Calculations For Towers

The unit cost is CAN \$2000 ([Conceptual Engineering Report Final 080211](#))

The unit quantity is  $m^3$

The total value for two towers is  $7,278.768 m^3$  and

$$7,278.768 \times 2000 = \text{CAN } \$14,557,536.00$$

### **Sample Calculations For Piers (Substructures)**

The unit quantity is  $m^3$  ([Conceptual Engineering Report Final 080211](#))

The unit cost is CAN \$2200

The total value for concrete footing type 2 is 36,199.09  $m^3$  and

$$36,199.09 \times 2200 = \text{CAN } \$79,637,998.00$$

### **Sample Calculations For Cables**

The unit cost of cables is CAN \$2000 ([Conceptual Engineering Report Final 080211](#)), and the unit quantity is  $m$ , yielding a total value of 9,584.75  $m$  and

$$9,584.75 \times 2000 = \text{CAN } \$19,196,500.00$$

### **Sample Calculations For Deck**

The main purpose of a bridge is the deck slab, which allows vehicles and pedestrians to cross the bridge with ease.

The unit quantity of deck is  $m^3$

The unit cost is CAN \$2000 ([Conceptual Engineering Report Final 080211](#))

The total value for deck is 119,034.261  $m^3$  and

$$119,034.261 \times 2000 = \text{CAN } \$238,068,522.00$$

### **Sample Calculations For Reinforcement**

The unit quantity is  $kg$ , and the unit cost is CAN \$2.65 ([Conceptual Engineering Report Final 080211](#)). The total value for reinforcement is 23,156,451.351  $kg$  and

$$23,156,451.351 \times 2.65 = \text{CAN } \$61,364,596.08$$

### **Sample Calculations For Asphalt**

The unit quantity is  $ton$ , and the unit cost is CAN \$976 according to Canada price 2015 ([Site Sections](#)). The total value for asphalt is 2706.87  $ton$  and

$$2706.87 \times 967 = \text{CAN } \$2,617,534.29$$

**Table 5.2: Cost estimation for scenario 1**

Task Name	Cost estimation				
	Quantity	Total Volume m3	Unit Cost CAN \$	Total Cost 2008	Total Cost \$ 2015
Drives Piles	422	32,833.52	\$ 588.60	\$ 19,325,809.87	\$ 21,486,566.79
Concrete footing type 1	83	23,557.396	\$ 588.60	\$ 13,865,883.29	\$ 15,416,183.30
Concrete footing type 2 (Mat)	1	1,586.414	\$ 588.60	\$ 933,763.28	\$ 1,038,164.36
Abutments	2	2,213.2	\$ 588.60	\$ 1,302,689.52	\$ 1,448,339.06
Towers	2	7,278.768	\$ 2,000.00	\$ 14,557,536.00	\$ 16,185,167.48
Piers (Substructures)	83	36,199.09	\$ 2,200.00	\$ 79,637,998.00	\$ 88,542,067.54
Deck	2	121,404.70	\$ 2,000.00	\$ 242,809,408.70	\$ 269,957,151.18
Reinforcement	1	23,156,451.351 kg	\$ 2.65	\$ 61,364,596.08	\$ 68,225,575.07
Cables	88	9,584.75 m	\$ 2,000.00	\$ 19,169,500.00	\$ 21,312,780.41
Asphalt	2	2706.87 ton	\$ 967.00	\$ 2,617,534.29	\$ 2,617,534.29
<b>TOTAL</b>				<b>\$ 455,584,719.03</b>	<b>\$ 506,229,529.48</b>

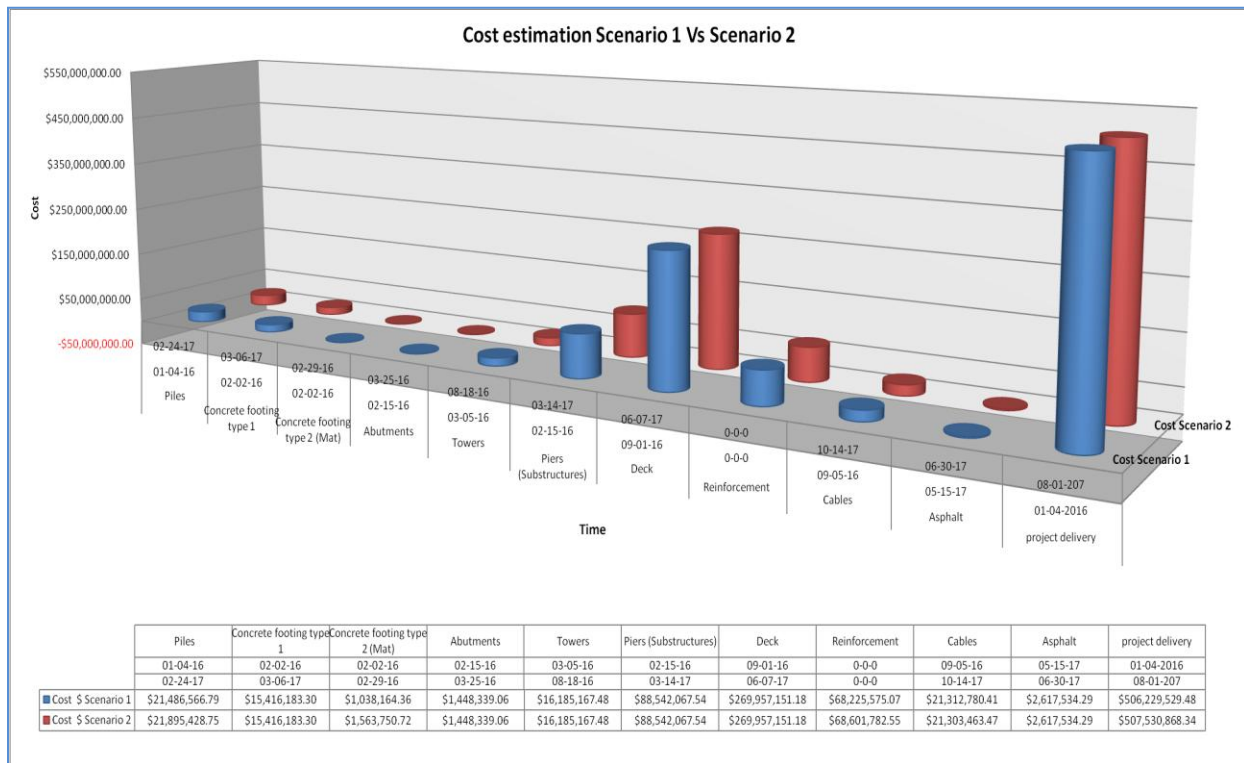
**Scenario 2****Table 5.3: Cost estimation for scenario 2**

Task Name	Cost estimation				
	Quantity	Total Volume m3	Unit Cost CAN \$	Total Cost 2008	Total Cost \$ 2015
Drives Piles	430	33,458.3	\$ 588.60	\$ 19,693,555.38	\$ 21,895,428.75
Concrete footing type 1	83	23,557.396	\$ 588.60	\$ 13,865,883.29	\$ 15,416,183.30
Concrete footing type 2 (Mat)	2	2,389.56	\$ 588.60	\$ 1,406,495.02	\$ 1,563,750.72
Abutments	2	2,213.2	\$ 588.60	\$ 1,302,689.52	\$ 1,448,339.06
Towers	2	7,078.768	\$ 2,000.00	\$ 14,557,536.00	\$ 16,185,167.48
Piers (Substructures)	83	36,199.09	\$ 2,200.00	\$ 79,637,998.00	\$ 88,542,067.54
Deck	2	121,404.70	\$ 2,000.00	\$ 242,809,408.70	\$ 269,957,151.18
Reinforcement	1	23,284,139.98 kg	\$ 2.65	\$ 61,702,970.95	\$ 68,601,782.55
Cables	88	9,580.56 m	\$ 2,000.00	\$ 19,161,120.00	\$ 21,303,463.47
Asphalt	2	2706.87 ton	\$ 967.00	\$ 2,617,534.29	\$ 2,617,534.29
<b>TOTAL</b>				<b>\$ 456,755,170.16</b>	<b>\$ 507,530,868.34</b>

Finally, the total cost estimation for scenario (1) is CAN \$506,229,529.48 and CAN \$507,530,868.34 for scenario (2). One can infer that both scenarios do not have a significantly big difference. The main difference lies in the locations of towers. In scenario (1) the towers for both sides are in the same area, while in scenario (2), they are in different areas, causing a price increase in scenario (2). Therefore, the concrete footing (mat) increased from 1,586.414 to



2,389.56 m<sup>3</sup>, and piles increased from 32,833.52 to 33,458.3 m<sup>3</sup>. Figure 5.11 shows the comparison between two scenarios, for all project phases including towers, deck, cables etc. As mentioned earlier, there is some disparity in pricing between scenarios due the difference in the towers' site, which clearly reflects the difference of cost between project stages as well as between scenarios. These increases evidently led to a total rise in project cost. However, the prices are frequently subject to change, which will lead to several problems and risks during the project implementation if the cost estimation is not updated automatically.



**Figure 5.11: Cost estimation comparison among scenario 1 and 2**

### 5.3.2 Cost Estimation by Using BIM System

In this section, we used Nevaris software by importing the project data from Allplan software. We calculated the cost estimate according to the materials and design that were determined from the BIM system. The cost and materials are represented relative to German markets, and the unit price is represented according to the Canadian dollar. This data was updated by the company, which supports the BIM system. However, the effects of these prices on the project were more realistic in that the unit prices can be updated automatically, which leads to the stability of the project costs and reduces the possibility of facing problems during the implementation stage of the project.

Moreover, this system works to calculate the project costs in a short amount of time and does not require significant experience. In addition, these unit prices can be updated with minimal effort if the Canadian market data is made available. The advantages of BIM are that it is easy to change or modify the prices manually, while some negatives of this software include that it does not support Canadian markets. This may have a significant impact when determining the final project cost because of the difference in the quality of the materials as well as the difference in prices between countries.

### Scenarios

By using Nevaris (BIM) we have calculated complete project costs stages, as shown in Figures 5.12 and 5.13, which show both scenarios (1 and 2). These tables include the prices, units, and unit prices etc, for each item, as well as the final cost of the project. Whereas, in scenario (1) the form work cost is CAN \$35,425,835.92; in scenario (2), it is CAN \$35,548,740.48. This is due to the difference in quantities. Moreover, the cables in scenario (1) are CAN \$4,641,698.15, while in scenario (2) they are CAN \$4,639,846.29. This is due to the difference in the tower's site, which led to the difference in the lengths of the cables. The results shown in Figure 5.14 exhibit the differences in cost between scenarios 1 and 2. This difference is CAN \$740,943.50. In this case, the cost in scenario 2 is higher compared to that of scenario 1.

## Scenario 1

Bill of quantities: 2015 - DEMO Bill of Quantities				New Champlain Bridge Scenario 1								Search
Reference number	Codetext	Type	Short text	Quantity	Unit	Unit price	Amount	C., DIN276:1981	Gewerkegliederung...	DIN276-1:2008-12		
<b>BoQ DEMO Bill of Quantities</b>							<b>506,026,235.85</b>					
<b>02</b>	<b>02</b>	<b>T1</b>	<b>SUBSTRUCTURE</b>				<b>79,974,860.19</b>					
<b>02.02</b>	<b>013</b>	<b>T2</b>	<b>CONCRETE AND REINFORCED CONCR...</b>				<b>79,974,860.19</b>					
02.02.480	013_014	I	mesh reinforcement	27,667,019.109	kg	1.175	32,508,747.45		013 Betonarbeiten	300 Bauwerk - Baukonstruktionen		
02.02.490	013_015	I	Betonstabstahl (f. Kostenberechnung)	10,247,044.091	kg	1.175	12,040,276.81		013 Betonarbeiten	300 Bauwerk - Baukonstruktionen		
02.02.510	013_017	I	form work	2,512,470.633	m2	14.100	35,425,835.93		013 Betonarbeiten	330 Außenwände		
<b>06</b>	<b>06</b>	<b>T1</b>	<b>BRIDGE PARTS</b>				<b>426,051,375.66</b>					
<b>06.1</b>	<b>061</b>	<b>T2</b>	<b>concrete parts</b>				<b>421,409,677.51</b>					
06.1.10	013_020	I	reinforced concrete bridge pier	1,024,704.383	m3	411.250	421,409,677.51		013 Betonarbeiten	331 Tragende Außenwände		
<b>06.2</b>	<b>062</b>	<b>T2</b>	<b>steel cable</b>				<b>4,641,698.15</b>					
06.2.10	100_001	I	steel cable	11,286.804	m	411.250	4,641,698.15		017 Stahlbauarbeiten	370 Baukonstruktive Einbauten		

**Figure 5.12: Cost estimation by using BIM software in scenario 1**

## Scenario 2

Bill of quantities: 2015 - DEMO Bill of Quantities				New Champlain Bridge Scenario 2								
Reference number	Codetext	Type	Short text	Quantity	Unit	Unit price	Amount	C., DIN276:1981	DIN276-1:2008-12	Gewerkegliederung...		
<b>BoQ DEMO Bill of Quantities</b>							<b>506,767,179.35</b>					
<b>02</b>	<b>02</b>	<b>T1</b>	<b>SUBSTRUCTURE</b>				<b>80,224,178.58</b>					
<b>02.02</b>	<b>013</b>	<b>T2</b>	<b>CONCRETE AND REINFORCED CONCR...</b>				<b>80,224,178.58</b>					
02.02.480	013_014	I	mesh reinforcement	27,763,368.563	kg	1.175	32,621,958.06		300 Bauwerk - Baukon	013 Betonarbeiten		
02.02.490	013_015	I	Betonstabstahl (f. Kostenberechnung)	10,258,280.884	kg	1.175	12,053,480.04		300 Bauwerk - Baukon	013 Betonarbeiten		
02.02.510	013_017	I	form work	2,521,187.268	m2	14.100	35,548,740.48		330 Außenwände	013 Betonarbeiten		
<b>06</b>	<b>06</b>	<b>T1</b>	<b>BRIDGE PARTS</b>				<b>426,543,000.77</b>					
<b>06.1</b>	<b>061</b>	<b>T2</b>	<b>concrete parts</b>				<b>421,903,154.48</b>					
06.1.10	013_020	I	reinforced concrete bridge pier	1,025,904.327	m3	411.250	421,903,154.48		331 Tragende Außenw	013 Betonarbeiten		
<b>06.2</b>	<b>062</b>	<b>T2</b>	<b>steel cable</b>				<b>4,639,846.29</b>					
06.2.10	100_001	I	steel cable	11,282.301	m	411.250	4,639,846.29		370 Baukonstruktive E	017 Stahlbauarbeiten		

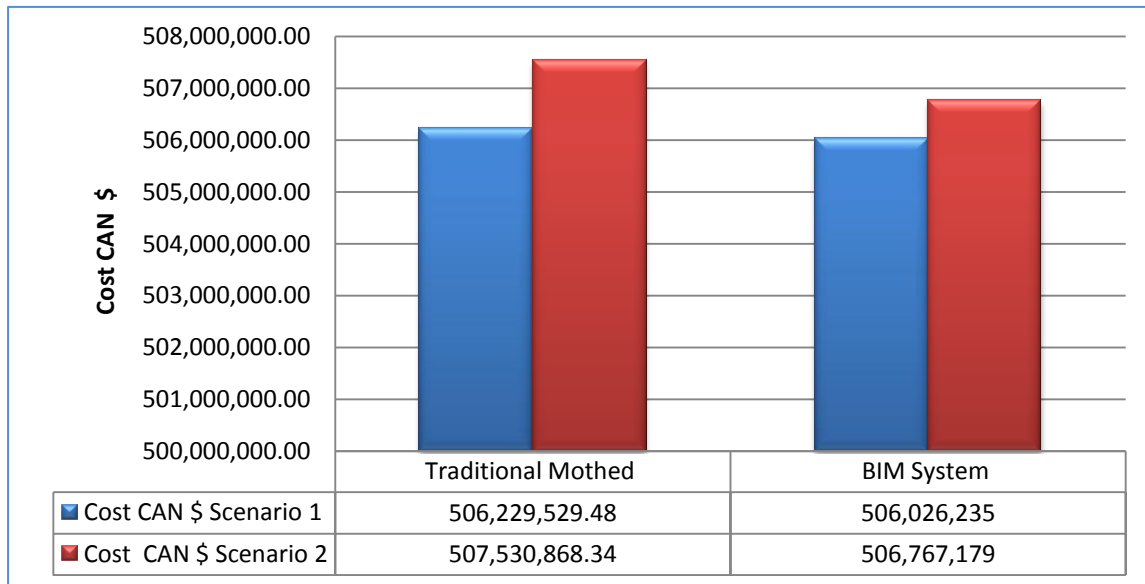
**Figure 5.13: Cost estimation by using BIM software in scenario 2**

Eigene Adresse							
Project:							
Variant comparison:		Across projects					
Variant comparison quantities and costs							
Currency in --							
2015		New Champlain Bridge Scenario 1					
2015		New Champlain Bridge Scenario 2					
Codetext	Name	New Champlain Bridge Scenario 1			New Champlain Bridge Scenario 2		
		Quantity	Amount	difference	Quantity	Amount	difference
	<b>Grand total</b>		<b>506,026,235.</b>			<b>506,767,179.</b>	<b>740,943.50</b>
013	CONCRETE AND REINFORCED CONCRETE WORK		79,974,860.1			80,224,178.5	249,318.39
013_014	mesh reinforcement	27,667,019.10	32,508,747.45		27,763,368.56	32,621,958.06	113,210.61
013_015	Betonstabstahl (f. Kostenberechnung)	10,247,044.09	12,040,276.81		10,258,280.88	12,053,480.04	13,203.23
013_017	form work	2,512,470.633	35,425,835.93		2,521,187.268	35,548,740.48	122,904.55
013_020	reinforced concrete bridge pier	1,024,704.383	421,409,677.5		1,025,904.327	421,903,154.4	493,476.97
02	SUBSTRUCTURE		79,974,860.1			80,224,178.5	249,318.39
06	BRIDGE PARTS		426,051,375.			426,543,000.	491,625.11
061	concrete parts		421,409,677.			421,903,154.	493,476.97
062	steel cable		4,641,698.15			4,639,846.29	-1,851.86
100_001	steel cable	11,286.804	4,641,698.15		11,282.301	4,639,846.29	-1,851.86

**Figure 5.14: Cost estimation comparison by using BIM between scenarios 1 and 2**

Finally, according to our results as shown in Figure 5.15, we have determined that the cost estimated by using BIM systems is cheaper than by using the traditional method, so the project cost in scenario (1) is CAN \$506,229,529.48 by using traditional system, while by using the BIM system, it is CAN \$506,026,235. The difference between the two is CAN \$203,294.4. Similarly, the project cost in scenario (2) is CAN \$507,530,868.34 by using the traditional system, while by using the BIM system, it is CAN \$506,767,179, so the difference between both is CAN \$763,689.3. These results may be inaccurate for the following reason: the prices that we used in the BIM system were not determined according to Canadian markets, but rather according to the German markets. Because the Canadian markets do not support the BIM system, these results may be inaccurate compared to Canadian markets in 2015. However, this may also be explained by the inaccuracy in manual calculations by using the traditional system, because this system depends on inputting the data as mentioned earlier, which includes calculating the quantities manually. This would involve calculating the amount of concrete columns then inputting this value in the accounts as well as inputting the material prices manually. Using this logic, the project may be exposed to confounding variables, which were not taken into account. For example, this may include mistakes during the data input, which would lead to an increase in the project cost and would ultimately lead to instability in cost. The BIM system is more accurate, as it functions with more details when calculating cost for all project items. This software works to calculate project items or materials automatically, such as Columns or Piles according to local

standards. It gives us all project details in any desired units, as well as prices according to the new update, which means that this system is accurate when determining the quantities, costs and project delivery.



**Figure 5.15: Cost estimation comparison among traditional system and BIM system**

An example can be used to illustrate the difference between using the traditional system and the BIM system and how both systems can solve the problems during the project design or implement period. By using BIM, if we assume the prices of material in the markets increased without the designer's knowledge, the designer does not need to figure out the prices because BIM system works to update the prices automatically. Also the calculation of the project quantities in case of change or modification of the design is updated automatically. If the owner wanted to change or modify the project, using a traditional design, the designer would be bound to modify all project details manually in 2D and 3D, in addition to re-calculating the quantities. In this case, the system spends a long time in modifying or changing the project. As for the pricing, in this case, the designer is also bound to follow the market prices when using this system, all things are done manually by the designer. BIM leads to a reduction in project time and cost and reduces the problems that the project may face when using a traditional system.

### 5.3.2.1 Example of a Disruptive Scenarios

This point shows the difference among the traditional and the BIM system in two scenarios as in a real life as follow:

#### Scenario 1

If we assume in the middle of implementation project, the project faced a problem whether by using the BIM system or by Traditional system. The problem is mistake in a column location, in this case the project cost will increase.

According to our calculation:

- A. The time period of column implementation needs to be 7 days,
- B. The concrete cost for one column is CAN \$961,400,
- C. The reinforcement cost is CAN \$118,908.8,
- D. We assume that the number of labour to implement the column is 10 labours, and the salary for each labour is 50\$/h. So,  $50\$ \times 20h = \text{CAN } \$1000$  daily for one labour  $1000 \times 7 = \text{CAN } \$7000$ . The total labours for this column in 7 days therefore costs CAN \$49,000,
- E. We also assume that the removal the concrete cost CAN  $\$650/m^3$ . So,  $650\$ \times 436.13m^3 = \text{CAN } \$283,486.85$

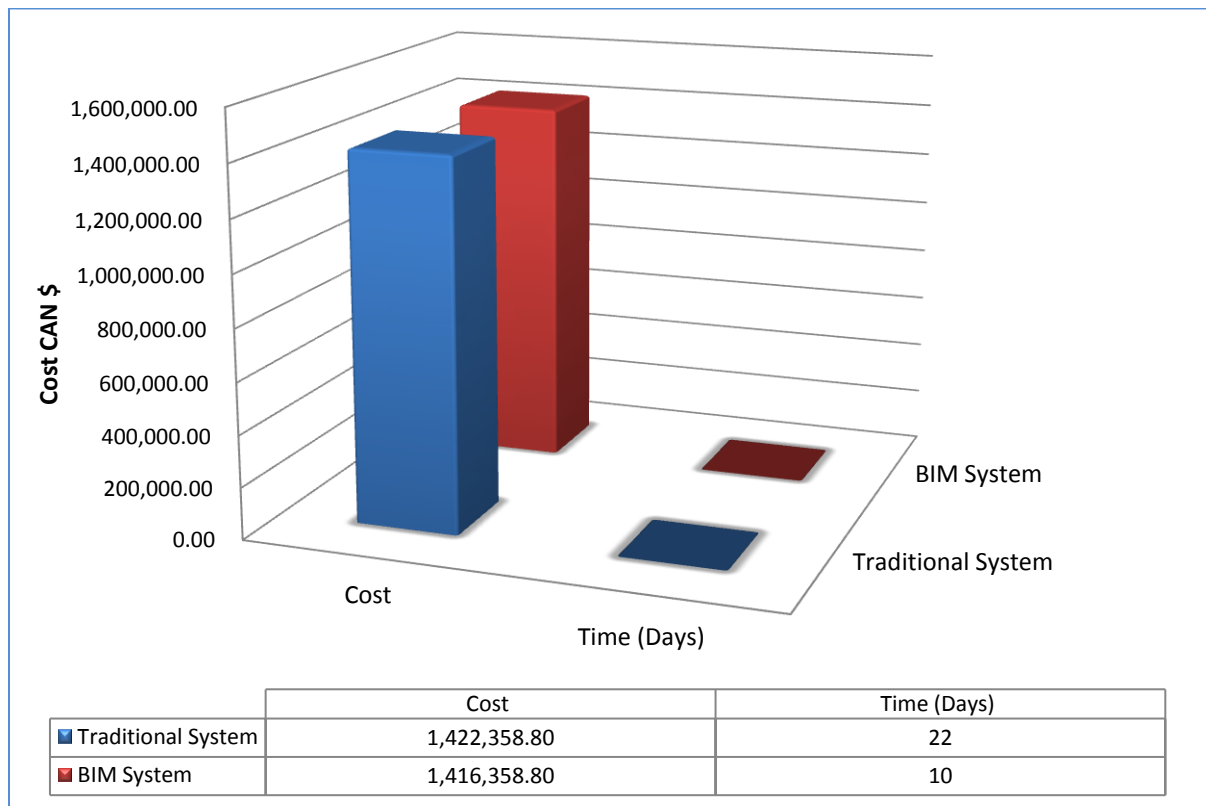
Therefore, the total cost of project increased to CAN \$1,413,358.8, and time delivery increased by seven days without the total cost and time to address this problem.

**First**, to address this problem using a BIM system, three days are required to perform modifications on the 2D & 3D designs and to calculate the quantity. In this case, the project time would increase to ten days in order to complete the project and would cost around \$3000 for modification.

**Second**, by using the traditional system, we need at least 15 days to modify the project. Because this system needs to modify a 2D plan, the other models includes any plate that show the column (e.g. sectors, and interfaces, etc). So, in this case, the time of project delivery will increase to 22 days. Additionally, the address cost will be around \$9,000.

**Finally**, as shown in Figure 5.16, the column time delivery and cost by using the BIM system will increase from CAN \$1,413,358.8 to CAN \$1,416,358.8, and the time from 7 to 10 days. On

the other hand, by using the traditional system, the cost will increase from CAN \$1,413,358.8 to CAN \$1,422,358.8 and time delivery from 7 to 21days.



**Figure 5.16: Example of a disruptive scenario 1**

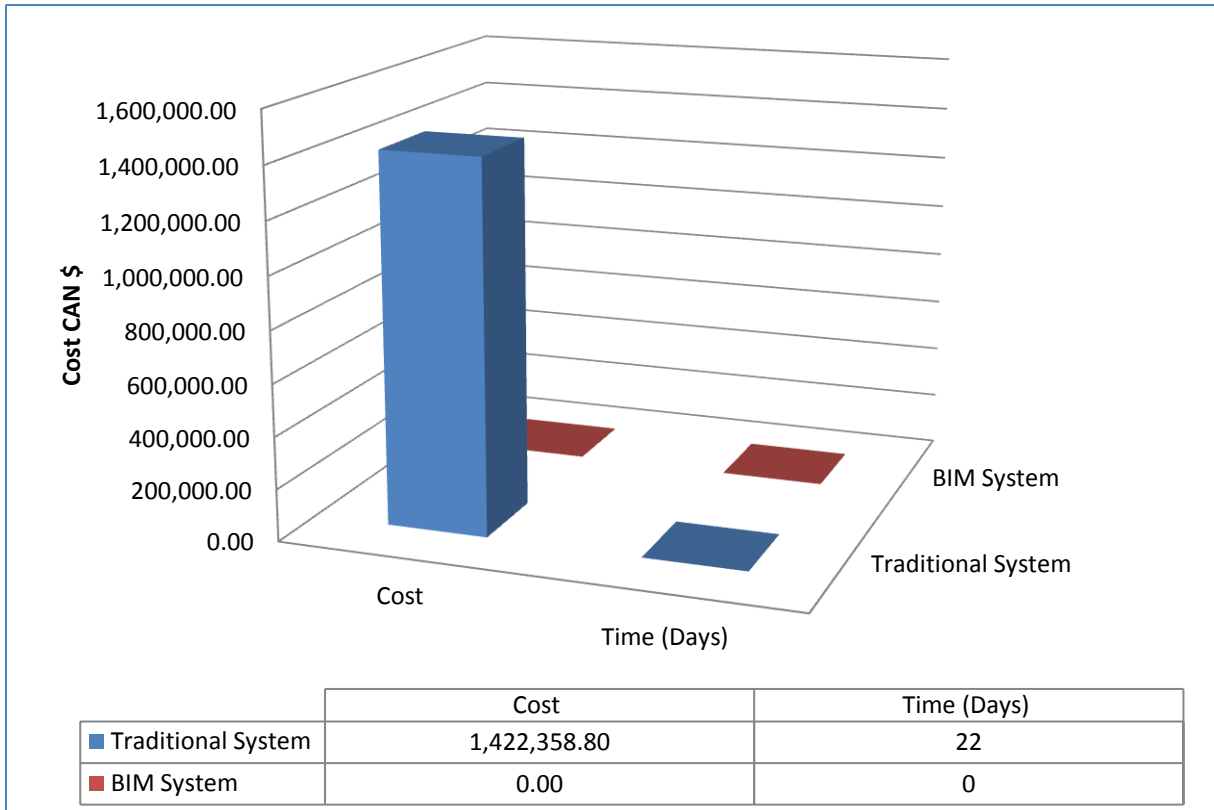
## Scenario 2

If we assume that there is a conflict between two columns, then both the BIM and traditional systems can address this problem. If the designer does not address this problem before the implementation stage, then the project cost and time delivery will increase the same amount as in scenario 1.

- A. 7 days (Column implementation),
- B. \$961,400 (Concrete cost),
- C. \$118,908.8 (Reinforcement cost),
- D. \$49,000 (Labours cost),
- E. \$283,486.85 (Removal the concrete)

**First**, when using the traditional system, it is difficult to predict any potential conflicts that may occur during the project design. In this case, the time of project delivery was concluded to be 22 days, and the project cost would be CAN \$1,422,358.8 more than the agreed cost.

**Second**, when using the BIM system, it is easy to detect any conflicts before the project implementation stage. By using the 4D BIM (simulation), the designer could acknowledge any problems that the project may face during the implementation period. In this case, the system will save around CAN \$1,416,358.8, and the project delivery time will be set according to the cost and agreed time to complete the project.



**Figure 5.17: Example of a disruptive scenario 2**

**Finally**, as shown in Figure 5.17, the column time delivery and cost by using the traditional system will increase to CAN \$1,422,358.8, and the time to 22 days. This value is additional to the total project cost and time delivery that was agreed upon in the contract. On the other hand, by using the BIM system, the cost and time delivery will be steady, according to the agreement in the contract.



## **CHAPTER 6     CONCLUDING REMARKS AND FUTURE DIRECTIONS**

In light of 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 option. This form of construction is characterized by its high strength, for example, it has a bearing strength of the environmental factors such as strong wind, and blizzards etc, and has strong concrete which may not be exposed to cracks for a long time period compared to the steel bridges. Moreover, the cables of this bridge are designed from rustproof steel, and architecturally, they will give off an impression distinctive from that of the city of Montreal. This new development may also lead to an increased level of tourism and a rise in the economic health of the region.

In this thesis design, we proposed the Cable-Stayed Bridge by using the traditional system and by comparing it to the BIM system. The traditional system, as we mentioned earlier, requires a long time to finish the project design due to its inability to integrate all data in one model as in BIM system. Therefore, the design process in this system takes a long time to modify. As well, experience is required to calculate the project quantities "manually" which are considered to be the foundation in determining the project schedule and the project costs. We proposed the project schedule, which includes the implementation of piles phase until the asphalt stage. Because of this, it was difficult to obtain the project schedules, which have been used for a New Champlain Bridge. However, we identified the timing of project stages, but we could not predict the existence of trammels, which might have been exposed to the project during the implementation period. The project may be facing problems that could lead to instability in the project delivery during a specific time period because of the difficulty we faced in predicting the project stages in real life.

For calculating the project costs "manually", as mentioned earlier, we used prices according to the Canadian markets in 2008 because of the difficulty involved in order to obtain the pricing of Canadian markets at the time the project took place. But we changed the prices according to Canadian pricing for 2015 by using the consumer price index (CPI) online according to data from the Bank of Canada. We obtained the results for project cost, and these results were accurate because the prices that we used may apply to prices at the moment. In addition, calculating the quantities by using this method may be inaccurate because these "manual" calculations may not

ensure accuracy, which is essential to the foundation for determining project cost. This may lead to increases in the project cost, such as mistakes in calculating the quantity of columns. The designer may therefore struggle to figure this out during the design period.

Therefore, we found that this system lacks important foundations for design, such as the flexibility of design, updating data, and difficulty to predict problems during the design period. The results suggest that the "traditional system" may leads to problems before and after the implementation period. These problems may include: spending long periods to modify or change the project, difficulties in figuring out the obstacles, increases in the project cost, unreliable logistics, resource and material management, and changes in delivery time.

Therefore, in this thesis we proposed using BIM system, as it is considered to be one of the smartest systems around the world, that Canada lacks to manage projects and to implement large-scale projects. Several countries, such as the UAE and China, use BIM regularly to implement large-scale projects. Indeed, BIM has an impact during the project's implementation and management phases and is considered a means to make the owner, contractor and designer know all of the project information before the implementation. It also aims to reduce the project costs, as well as deliver the projects at a specific time without facing any problems.

We have used a 3D BIM system to determine the land terrain that is considered the foundation to determine the project site and project foundations. We designed the project through inputting all the design data for each model, where the system outputted all these details as a 3D model including project reports and quantity take-off. The costs and scheduling of the project were then determined from there. Using a 3D BIM system allows for the ability to design the project in a limited time with flexibility and ease to change or modify the project. Inputting the data can be done with ease, including the type of material used during the design period, as this system integrates all information in one model. The 3D BIM system also has the ability to make design iterations more than once and to deliver the project as a PDF file, which helps the owner and contractor to see and figure out all project details (3D) without resorting to using the software that requires experience. Moreover, delivery of the project reports is done in one hour or less which includes all details presented as a PDF or spreadsheet file, and displays the 3D project in real life.

We have used a 4D model, which means "Scheduling and Simulation", to determine the project phases by using the TIM software. We assumed the schedule for all project stages, because BIM

system does not support time calculation automatically, the time calculation in traditional system. When inputting the data which includes the schedule, cost and all other project details, the software directly shows the results of the project in a real life simulation. These results lead to knowledge of all details, which includes time and cost for each stage as well as all obstacles that the project may face during the implementation period. For example, conflicts between two items and allowing us to predict all project phases with ease.

We have also used a 5D model for cost estimation, according to the quantity take-off. We calculated the project costs by using Nevaris and the prices were set according to the German and Austrian markets. As previously mentioned, this system does not support Canadian markets, whereas the currency were Canadian "CAD \$". The 5D BIM showed the ability to change or modify the data manually, to update the prices of data automatically, and to deliver the project reports for stakeholders and contractors as a PDF or spreadsheet file. The results were realistic but may be inaccurate, because these prices were determined according to another country, which is Germany. The 5D BIM system has the ability to modify the prices according to the Canadian markets by inputting all project prices by using the periodic data provided by RSMeans. This enterprise provides all the construction cost information throughout North America.

These results suggest that BIM most likely has a positive impact on design and project management, and may lead to cost reduction, better time management, profitability, ease in prediction of the future, information flow, and improved relationships between owners, contractors, and designers. We also performed a comparative analysis between the traditional method and the BIM system, and we assumed some problems during project implementation and during the project design period. In order to know how the traditional and BIM systems can solve these issues. By using the BIM system, the project saved 15 days compared to when using the traditional system to deliver the project. As well, BIM also saved around CAN \$6,000 compared to the traditional system, as in the first scenario. Moreover, in the second scenario, the results were determined using BIM, which made it easy to predict if there was any conflict during the project design period. However, by using the traditional system, it was difficult to predict if there were any conflicts. The results suggest that building the bridge using BIM will provide several advantages such as flexibility of design and delivery, a more detailed analysis of project cost, easy availability of detailed information on every stage of the project for all the stakeholders, and a clear understanding of the project phases by using sophisticated simulations.

As a next step, we want to include a more detailed representation of the terrain and the structural design in the BIM system; therefore we propose to develop Allplan software to prepare the land terrain points as in the SketchUp software, so as to provide time during the design. We develop a 4D model, called "Schedule and Simulation", in order to prepare the project schedule automatically, so as to get on a schedule for all project phases with a high accuracy.

In addition, we propose to link the 5D model "Cost estimation" with Canadian markets (such as RSMeans) to implement the projects with the lowest costs. We also propose to provide the BIM system in universities for training for several reasons: the students can learn about the smart technology that addresses the problems that face the projects during their implementation. As well, it can help students to get a job in their field because most companies require work experience of more than five years. Therefore, according to our future expectations, BIM will be a means to not only implement the large-scale projects, but also to provide a job for students in their field.

We intend on integrating the 6D model "Facility management" into part of the design of a New Champlain Bridge because a 6D model provides other project details, such as workers movement. It also allows for easy following and management of the projects after implementation (maintenance). We also plan to integrate the 7D model, "Sustainability", which is considered to be very important for project design as it estimates the energy with high accuracy. This will save the energy consumption used in the project for "Green building". We will also integrate the 8D model, "Occupational Safety and Health" as part of the project design because 8D model is very important in providing safety for workers and stakeholders during the project performance, which may lead to saving time and money in the long run. In addition, we intend on working closely with the industry to promote the use of BIM systems in transportation infrastructure projects, so as to provide a link between software and North American Infrastructure markets. The BIM system will also help the government of Canada save money and will aid in implementing projects in record time without facing problems that many current projects face.

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