VISUALIZING THE DESIGN AND CONSTRUCTION OF ROADWAY SYSTEM: A CASE STUDY

by

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ABSTRACT

Effective planning and scheduling of construction operations is critical for the success of any construction project. Visualization tools provide engineers with more understanding of and insight into construction project information. The main objective of this research is to investigate the capabilities of existing state-of-the-art software to create realistic visualizations of the design and construction of transportation systems. This research was funded by the Ministry of Transportation, which requires realistic visualizations of their transportation projects to communicate with different stakeholders.

The research focused on part of the South Fraser Perimeter Road project, which is part of the Gateway Program. The project included a four-lane, 490m bridge and approaches to the bridge. To provide a visualization of the construction process, I utilized existing 4D (3D + time) modeling tools. In this method, a 3D model of the bridge is connected to the construction schedule to create an animation of the construction process that represents how and when the structure will be built. I also utilized landscape visualization software to enhance the realism of the project surroundings.

During the course of this project, I learned many lessons regarding the capabilities of the software tools. The process of 3D modeling should be accomplished with constant connection with the designer and client, and the 3D design process should be planned beforehand. Also, the scale and position of each object and its relation to other objects in the 3D model should be carefully considered before exporting to 4D software. In the 4D modeling process, the schedule should be reviewed thoroughly before connecting each task to the 3D objects in the 4D model. Finally, 4D modeling software has limited rendering power. To create truly realistic renderings requires more powerful software tools, which currently have limited compatibility with 4D software.

In this case study, I found that although there is room for improvement, existing technologies are capable of creating effective visualizations of the construction process that are helpful in communicating to a variety of stakeholders. However, significant work is needed to develop visualizations that are capable of realistically representing the project environment.

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Dedicated To ….

My Parents, for Their Life-Long Support and Love,

and

My Wife, for Her Love and Patience,

and

Those Who Had the Talent but Never Got a Chance.

CHAPTER 1
INTRODUCTION

1.1 RESEARCH MOTIVATION

Construction industry provides a competitive market to all aspects of Information Technology to speed up completion of projects and optimize decision making and planning process. Also, enhancing design capabilities by using features like walkthrough's, interference check and design review, have cut down rework on site. On the other hand, very little attention is given to visualization of the construction process which is planning the actual operations that comprise activities, and contribute to the completion of a physical facility component or the performance of a support service (Howell & Ballard 1999; AbouRizk, Simaan and Halpin 1992). Moreover, in spite of about two decades research on 4D modeling, this aspect of visualization technology has not been utilized in its full potential and capability in the construction industry, as well. However, there are many off the shelf systems for various features of visualization technology such as 4D CAD, which can be implemented and used effectively to gain more market share and profits in the construction industry.

Success on construction projects requires effective execution at the operations level (Oglesby et al. 1989). Therefore, proper planning of operations is required. Visualization techniques can be considered for construction operations in order to visualize what is going to happen during construction and to help project managers and planners in their decision making process.

Effective planning and scheduling of construction operations is critical for the success of any construction project, irrespective of its magnitude. As such, the planner's judgment, imagination, intuition, and experience are relied upon heavily to ensure success. This often compels the planner to develop a mental model of the actual construction process and the sequence of various activities and operations involved therein. This can be a demanding task in today's technically advanced construction scenarios (Kamat 2000).

The motivation for conducting this research in the area of construction visualization (or virtual reality in construction) can be categorized in two main parts: the construction industry's increasing demands of visualization to optimize the construction process, and technological opportunities due to the advancement of software and hardware which is capable of depicting construction operations in 3D.

1.1.1 Industry Needs

The ability to build facilities virtually before expending real resources has been of main interest to many constructors over a long period of time. Achieving this goal, they will visualize their operations on computer generated jobsites, and study differences between alternate plans with speed and accuracy. They can also design their operations so well that when they construct real facilities, they will encounter no surprises (Behzadan and Kamat, 2005).

Nowadays, the construction industry needs effective approaches for representing or visualizing data relating to construction activities such as performance information, design, cost and schedule, in order to enhance the planning and decision making process. Construction companies are motivated by different driving factors to use visualization capabilities in their projects. As an illustration, in the current competitive market, their rivals are using these tools to get more projects and profits by showing their plans and construction process in a virtual environment. Also, there is very low gestation periods for design and project starting periods because of the use of these visualization tools which can give a company much needed edge in the market. Further, there are varying requirements of the clients and the need to satisfy all of them through using these kinds of tools for getting the projects in the first place or presenting the progress during the construction.

Moreover, factors such as market conditions, productivity increases, cost and constructability for project planning and development, as well as visualization of the conceptual design can motivate construction industry to utilize visualization tools. Other parameters that take part in driving companies to use this new technology are: savings in scheduling processes, reduction in rework on the project, the value adding capability of these tools to the project management process, and marketing advantages. Finally, improvements in quality and safety, savings on project costs, standardization of processes, saving replication and in recent years, environmental issues can be considered as the motivation factors for construction industry in order to come to visualization tools in their projects.

Singh (2002) categorized Electronic Simulation (ES) tools used in the construction industry as 3D CAD systems, Virtual Reality/Visualization Systems, Mathematical Simulation Systems, and Integrated Systems, based on the survey. The following chart (Figure 1) shows the results.

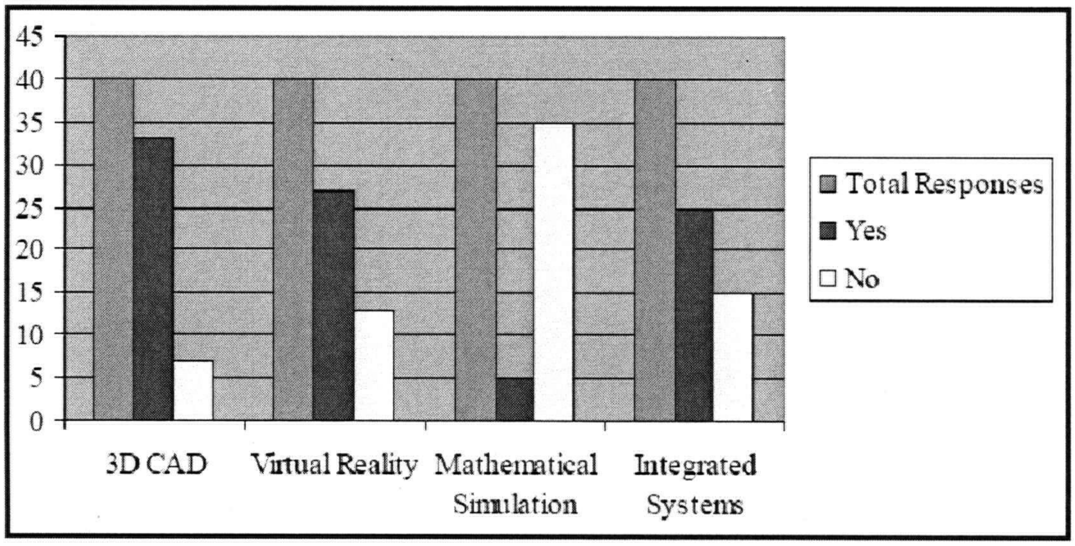


Figure 1: Number of respondents using any form of ES. Singh (2002)

The majority of the respondents of the survey used visualization tools for activities such as design interference checks, equipment installation and access, plant layout, maintenance and operations review, constructability, and construction interference checks. Several respondents mentioned minor use of visualizations tools in training, construction equipment and temporary construction facilities layouts, schedule progress monitoring, construction sequencing activity and material maintenance. This survey illustrates the industry's need for visualization tools to develop, improve and optimize the construction process.

1.1.2 Technological Opportunities

Generally, the technological changes going on in the visualization techniques with respect to advancement in computer software and hardware provide many state of the art tools in various aspect of virtual reality that can provide reliable sources for construction industry to perform a given project more effectively and efficiently.

Today there are a variety of computational resources available to visualization. While a huge number of users are content with the visualization capabilities provided through modern desktop computers and powerful 3D graphics accelerators, many are still relying on high-performance computing facilities to visualize very large datasets or to achieve real-time performance in rendering a complex visualization. "In some areas, users have already demanded visualization capabilities to be provided through mobile computing systems, such as PDAs (Personal Digital Assistants), most of which are yet to benefit from powerful 3D graphics accelerators" (Brodlie et al., 2005).

Among all existing technological advancement and visualization techniques provided by developments in computer technology and other technological opportunities, virtual environments represent a major technical drive in computer graphics and visualization, and have helped push a range of hardware and software technologies forward. This environment enables users to be immersed inside a computer generated world with a sense of spatial presence and often physical presence. For many visualization applications in construction industry, virtual environments can provide users with realistic experiences in 'interrogating', 'navigating within', 'feeling' and 'manipulating' data via its visual representation.

These characteristics of visualization technology which are developing along computer technology have become favorite approach for construction companies in recent years.

1.2 RESEARCH OBJECTIVES

Providing the most possible real virtual environment for construction operations in advance of the project, in order to increase the insights into the project plan, method and schedule was the main objective for this research. The realism must satisfy the expectations of the client and also convey the specification of the actual construction area.

In this research, specifying the highlights of state of the art 3D CAD, 4D CAD and Landscape Visualization tools, and identifying their limitations for using in construction visualization projects was mainly considered. For this purpose, 3D and 4D models of a bridge have to be built. Also, the landscape of the project area after the construction operations needed to be modeled. Moreover, virtual environment for simulating construction operations on the personal computer using available technology was developed by utilizing 4D modeling visualization tools.

Various software tools such as Autodesk Architectural Desktop, Visual Nature Studio, NavisWorks and 3D Studio Max were explored during visualization modeling. The capabilities of them for using as visualization tools in construction industry needed to be assessed. The result of this evaluation was explanation of the benefits and limitations along with some critiques.

Finally, during the interaction with the client and designer of the bridge, the usefulness of 3D/4D CAD tools during the planning and scheduling of the projects by planners with different levels of practical experience was investigated. Also, the effects of using landscape visualization in the process of construction operation visualization with the aim of providing a better understanding of the project's surroundings were investigated.

1.3 RESEARCH METHODOLOGY

During this research, it will be tried to show the usefulness of visualization power and benefits for virtually modeling construction operations prior to actual construction. With the aim of accomplishing the research objectives the research work was categorized into three main stages:

1- Literature Review

Thorough literature review was done during this research to explore what has been done in the area of visualization in construction, construction simulation and virtual reality in the construction industry. During this stage of research, I investigated previous and on-going research, identified research needs, and positioned my research in this field.

2 - Evaluate 3D, 4D and Landscaping Software in Visualization Context

The first step of the project, learning and evaluating different sets of software began by experiencing various approaches to build 3D and 4D models in these advanced software tools. The collection of software included the 3D modeling software which was Autodesk Architectural Desktop, 4D modeling software which was NavisWorks and Landscaping software which was Visual Nature Studio. We tried to visualize construction operations of the bridge and its surrounding area as real as possible. All of these state-of-the-art tools helped me to visualize the construction project in the form of a case study, and gave me insight into the capabilities of some new tools in the area of visualization.

3 – Utilize the Software for the Case Study

In order to represent the benefits and problems of visualization tools in construction industry, I utilized aforementioned state-of-the-art software to develop a virtual model of construction operations for a bridge. The development process involved 3D modeling of a bridge, 4D modeling of the construction process and landscape modeling of the environment to convey the construction process to the stake-holders of the project.

1.4 THESIS ORGANIZATION

This chapter introduces the rational behind the thesis motivation, and describes the research objectives. Also, the scope of the dissertation and the methodology to achieve the research objectives in that scope is discussed.

Chapter two in the form of literature review explores previous research in the area of visualization in construction industry. This literature review starts with the outline of various researches about the meaning of visualization and the different types. Then, it overviews previous works in different aspects of visualization in construction such as visualization in Architectural, Engineering and Construction (AEC) industry, realistic visualization, landscape visualization, and the role of 3D/4D modeling in visualization.

Chapter three describes the Gateway Project that overviews project area, and the scope of our case study. Also, it introduces the project participants and their contribution to the project. Finally, it discusses the visualization needs in the Gateway Project.

Chapter four illustrates the whole procedure of 3D and 4D modeling in the case study. This illustration involve the introduction to the case study, the process of 3D modeling from the start of design to the creation of the models, and the process of 4D modeling including the development of Macro and Micro-level models. Also, this chapter critiques the utilized software and their abilities and benefits for construction visualization.

Chapter five represents the thesis summary and the conclusion of this research, the lessons learned and future directions for visualization in the construction industry.

CHAPTER 2
LITERATURE REVIEW

2.1 INTRODUCTION

Despite the fact that utilizing visualization tools and techniques in construction industry is rather new, many researches have been done in this area of research since three decades ago. In this chapter the essence of previous work in the field is presented.

There is a desire to see a few significant improvements as solving a range of problems in construction. Virtual reality is one of these and, while its present manifestation is just another stage in the development of visualization, its potential is for simulating buildings in many ways; not just their appearance but their performance and the process of constructing them as well (Howard, R. 1998). Edward Tufte (1990) in his book mentions that the most rewarding and challenging form of information graphics are compositions that convey multivariable data.

In construction industry each project has its own special attributes in terms of performing construction operations which stem from typical complicated interactions between construction's components such as equipment, labor trades, and material (Kamat and Martinez 2001).Various project stakeholders can have enhanced communication and coordination through using 3D models, as an integrated communication infrastructure, in order to gain similar conceptual image from the model of the planned project (Aspin, DaDalto et al. 2001).

These days, great advancements in computer technology, such as software and hardware development and web base collaboration tools, help professionals to accelerate design and construction tasks more efficiently than ever before. Lifelike animations such as those in computer games and animation movies can be produced through utilizing these available technologies, while there are no common usages of these kind of potential in construction industry.

More complex ideas can be represented by building 3D models without expanding the risks of construction errors. During the time that project participants review a model, better decisions will be made which lead the project to lower lifecycle costs. 3D models can explicitly provide insight evaluation into the order of construction, site safety, and location of temporary site facilities (Aspin, DaDalto et al. 2001).

State-of-the-art construction simulation tools permit the modeling of complex construction operations at any level of detail (Martinez and Ioannou 1999). These tools can provide detailed insights on modeled construction operations.

Simulation models are termed as "credible" when the models and their results are accepted as being valid, and are used as an aid in making decision (Law and Kelton 2000).Kamat (2003) believe that utilizing simulation and virtual reality for the construction process during the design stage is reasonable only if the provided information through 3D model help the planners in decision making and enhancing the comprehension of the project for the stakeholders which indicate the fact that the models should be credible.

Therefore, the needs for virtually constructed models in advance of the construction operation in order to enhance the performance of the process are obvious, and can be achieved through construction visualization process and utilizing the available tools (Kamat 2003, Carson 2002, Law and Kelton 2000, Rohrer 2000, Jain 1999, Henriksen 1998, Tucker et al 1998, Robinson 1997, Martinez and Ioannou 1996, Cox 1998, Biles and Wilson 1987).

"Visualization" in construction brings various meaning for different people. Particularly, the term has been used in the literature to refer to any kind of series of sequential computer frames without taking into account their origin and or their contents (Op Den Bosch 1994). Kamat (2003) defined visualization as "numerous computer-based visual activities that can be directly or indirectly used in construction planning". Many attempts and activities have been done in this area of work during past years which are summarized by Dr. Kamat in his PhD dissertation.

Nowadays, landscape visualization is also considered as part of construction visualization. Landscape visualization are picture of real places seen from particular perspective, which can be manipulated in countless ways to show features of importance or future conditions based on land management decisions. They can help everyone from children to elders; better understand how their land spaces will change (Sheppard, Lewis and Akai (2004)).

On the other hand, John Kunz (2000) pointed out that Architectural / Engineering / Construction (AEC) industry significantly improved visualization. In order to cope with the complexity of AEC projects and make them more understandable for all facility stakeholders, 3D visualization techniques seem to be a solution. There is still high potential available in this area of visualization and the opportunity is completely open.

In this project, I tried to assess methods to accurately represent and portray the realism and performance of modeled construction processes in dynamic 3D virtual worlds. In this section it will be tried to overview the literature in all aspects of the field of construction visualization which includes different types of visualization, visualization in AEC industry, Landscape visualization, 3D and 4D visualization, and their related State-of-the-art software.

2.2 TYPES OF VISUALIZATIONS

There are a wide range of activities involved in construction processes that range from basic works to complicated operations. Understand the plan and design of these construction operations which include many components is ineffective in conventional methods and can be enhanced through utilizing visualization tools (Kamat 2000).

Construction visualization has utilized available computer graphics and animation techniques regarding the advanced hardware and software technologies, although the utilization process does not accompany the advancement. The simulation process started with animating 2D CAD models on the computer screen, and progressed through 3D model presentation by using high speed computers and enhanced graphic (Naji 1997).

Numerous advances have been made in the area of construction operations modeling (Martinez & Ioannou 1999), but mostly the attention was on producing 3D models and their changes and developments through schedule time (4D models) while visualizing the construction operations has been given inadequate attempts (Kamat 2000).

The first attempt toward visualization was made by Hurrion (1976) through combining computer graphics and user interaction as the initial step for Visual Interactive Simulation (VIS) technique. Then, he supported this technique by developing SIMON which was a simulation language (Bell et al. 1987).Visual Interactive Modeling (VIM) was born in late 1979s as a result of computer technology advancement through the improvement of the input and modeling capabilities of VIS (Bishop et al. 1990).

In 1982, OPTIK was the first application which let the user define the simulation model while the simulation was running (Bell et al. 1987). With continuous improvements in VIS and VIM, simulation systems started to be used as modeling, simulation, and decision support systems (Opden Bosch, 1994). Visual output and user-interaction are the essential blocks of VIS. Potentials of VIS technique lead the researchers toward utilizing Virtual Reality (VR) as the real-time computer graphics in construction visualization. This new technology allows the user to step into a 3D virtual world and can be considered as the next step for the CAD animation technology which makes the visualization techniques closer to reality.

The results from literature shows that combining many disciplines including psychology, cybernetics, computer graphics, database design, real-time and distributed systems, electronics, robotics and multimedia provide a foundation for VR to be born. This new technology has been primarily utilized in various areas other than construction industry such as defense, aerospace, robotics and industrial automation.

One of the areas in which VR was investigated is the area of construction engineering. Computer Aided Building Design (CABD) tool can be considered as the outset of VR in late 1970s at the University of Reading in the United Kingdom which was developed later on (Werwick et al. 1993). Then, Interactive Visualizer Plus Plus (IV++) was developed in 1994 at the Georgia Institute of Technology in the United States (Opdenbosch, 1994). Moreover, a new technique called Computer Aided Design and Assembly (CADA) was developed in the VI++ which automates the process of simulating building construction (Opdenbosch, 1994 and Naji 1997)

In just past two decades, the science of computer simulation has evolved from very crude beginning to the three-dimensional, animated capabilities available today (Karami 1991). For simplicity, Ndekugri & Lansley (1992) classified simulation in construction into four general categories:

- Non-gaming simulation at the project level, such as Gantt charts, CPM, PERT, and GERT.
- Gaming simulation at the project level, for the purpose of teaching and training.
- Simulation at the level of site operation which includes repetitive construction operations such as concreting, bricklaying, truck movement, etc.
- Simulation at the corporate level, for example issues about strategy, organizational structure, the various functional areas of management.

Also, Sriprasert and Dawood (2003) categorized visual representation in construction in six different types: 1- Worksheet: uses for work-face instruction or method statement. 2-Bar chart or Gant chart: uses for planning, 3- Line-of-Balance: uses as a scheduling technique. 4- 2D drawings: uses for site layout and space planning. 5- 3D CAD: uses for wide range of activities such as clarification of detailed connections. 6- 4D CAD (3D CAD + time): uses for evaluation of schedule and plan and communication with project participants and stakeholders. This kind of visual representation will be discussed more in the next sections and chapters.

Akbas (2003) in his PhD thesis categorized previous works on construction process modeling and he summarized them in one diagram (Figure 2). This figure provides a framework of various works on and different types of visualization related efforts.

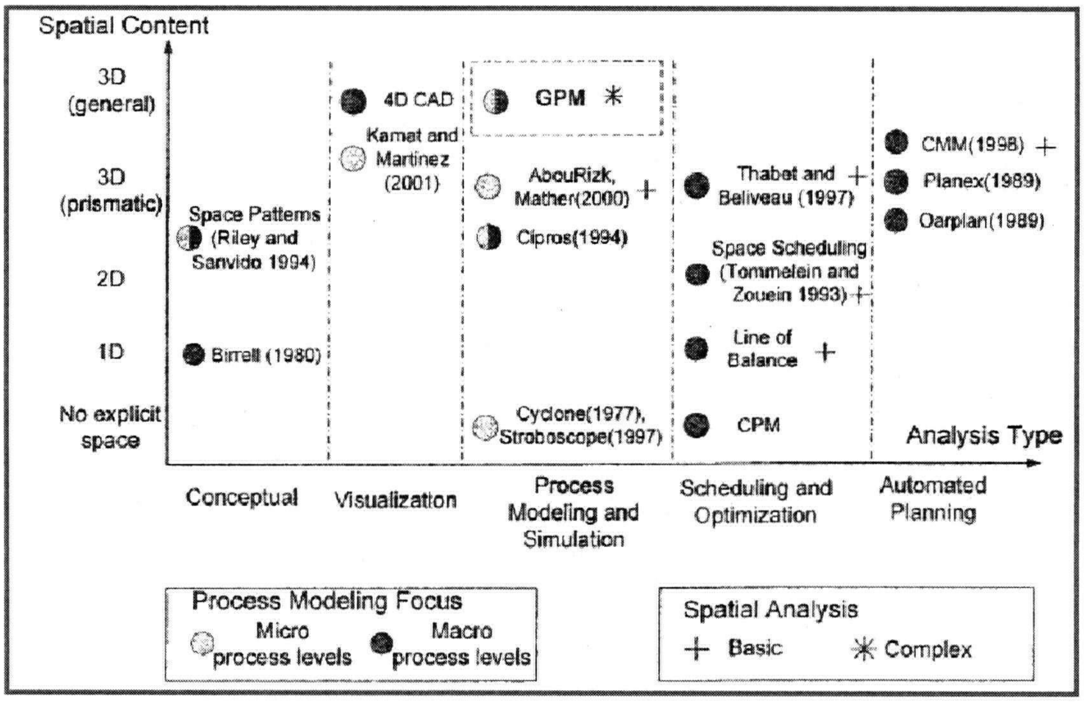


Figure 2: Categorization of related work in Geometry-Based Process Modeling, Akbas (2003)

Dr. Sheppard (2004) pointed out that there are several different types of Visualization, or to be more specific, Landscape Visualization as one of the most important components in construction visualization are available. They include, Sketching and painting done by hand, Physical 3D models, Computer Aided Design and Drafting (CADD) (e.g. AutoCAD), Photomontage or digital image processing of photographs (e.g. Photoshop), Landscape modeling with software packages (e.g. Visual Nature Studio), Full 3D model can represent features such as trees (e.g. OnyxTREE PRO) or buildings (e.g. 3D Studio).

These different types of visualization demonstrate a range of realism, from somewhat simple and abstract, to highly realistic. The varying levels of realism can be very important in determining how visualization is used. More realism in construction operation visualization can provide better understanding for project stakeholders and enhance method for project planners to find their error before any construction which can save time and money for companies.

2.3 VISUALIZATIONS RESEARCH IN AEC

Many diverse disciplines are involved in the Architecture, Engineering and Construction (AEC) industry. These disciplines range from architecture, structural and HVAC engineering, to cost estimation, and construction and facility management.

One of the dominant issues comes from communication and coordination of information through these various fields, although every one of these disciplines has its own terminology for defining in AEC projects. This problem is mainly extended in a global economy because many large AEC projects are now undertaken by groups of companies whose staff are distributed in different offices worldwide.

Although hardware and software technologies have been significantly advanced in recent years, especially in Computer-Aided Design CAD, and have contributed to the development of more powerful and easier-to-use tools for managing and communicating AEC information, most integrated AEC software systems still remain "Islands of Automation"(Zamanian , Pittman 1999).

Kunz (2000) believes that in about 25 years the AEC industry will alter "fundamentally" with respect to serious effects from computer developments on "AEC professional practice". On the other hand, Chaaya and Jaafar (2001) stated that Computer-Aided Design (CAD) systems are not being fully utilized in the AEC industry even though they are extremely powerful tools. Song (2004) thinks that so far these virtual models have only been partially used for automation in the architect or engineer's specialization.

It is also believed that the 3D model not only has values as a tool for design expression, but it is a central information platform for gathering, organizing, recording, and distributing various information on the overall project (Tarandi 2003).

Architectural design has been the main driving force for developments in 3D modeling and Virtual Reality (VR). By allowing architects to visualize and immerse themselves in their designs, a much clearer understanding is gained of both the qualitative and quantitative nature of the space they are designing. Visualization and VR enable designers to assess proportion and scale using intuitive interactive modeling environments (Kurmann and Sculptor, 1995) and simulate the effects of lighting, ventilation and acoustics in internal environments (Shinomiya, et al. 1994; Nimeroff, Simoncelli, Badler and Dorsey, 1995).

The use of visualization in this area also includes the simulation of egress from buildings for the design of fire escape routes (Spearpoint, 1994). As a visualization tool VR is also used to communicate design ideas from designers to clients by generating walkthrough models to test the design with the clients in a more direct manner (Ormerod and Aouad, 1997).

Further, in order to visualize, simulate and monitor site progress visualization techniques can also be used to model the construction sequence. This is done using a "pre-prepared library" of objects, and produce models illustrating views of the construction sequence at any given time of the process (Adeji-Kumi and A. Retik, 1997).

At a larger scale of visualization Web-based Virtual Reality techniques generated a lot of activity in Urban Modeling which led to the introduction of the concept of "Virtual Cities" (Day, 1994). The most popular approach in the development of these 3D models is using VRML (Virtual Reality Modeling Language), which is a Web modeling language that is able to construct objects in three dimensions.

Currently, various commercial software tools for the AEC industry (such as Autodesk Architectural Desktop, Graphisoft's ArchiCAD, Microsoft's Visio and Timberline's Precision Estimator) are beginning to implement Industry Foundation Class (IFC) file exchange capabilities (Froese 2003). Project information in a number of diverse systems, based on IFC standards, can be accessed concurrently by many users, or can enable transactional forms of data exchange among project participants and applications.

Recently, like other visualization applications in various aspects of construction, utilizing visualization techniques in AEC, due to its complexity of both product and process is required by many clients. This technology helps project participants and stakeholders to comprehend complicated procedure in AEC industry (Kunz 2000).

With the aim of collaborating in the design of new buildings, and regarding the increase in specialization of AEC disciplines, existence of huge demand on the communication media used by these disciplines are obvious and understandable. Realizing the potential advances in these technologies in collaboration with AEC industry has been limited by the conventions, methods, procedures and practices used by these disciplines (Song, 2004).

Song (2004) conducted an interview with four professionals in different fields of the AEC industry, regarding the efficiency of the system currently used in each professional's work.

Their feedback on the potential value of the 3D model based system of improving the work in each field through prototype presentation was also gathered. Only because there was a lot of overlapping feedback from the interviewees, those comments with greatest value from each professional's perspective are summarized in Figure 3 below. It can be comprehended from the results that the usage of 3D visualization tools covers somehow broad range of tasks in AEC industry, although currently the utilization of such techniques is not widely common.

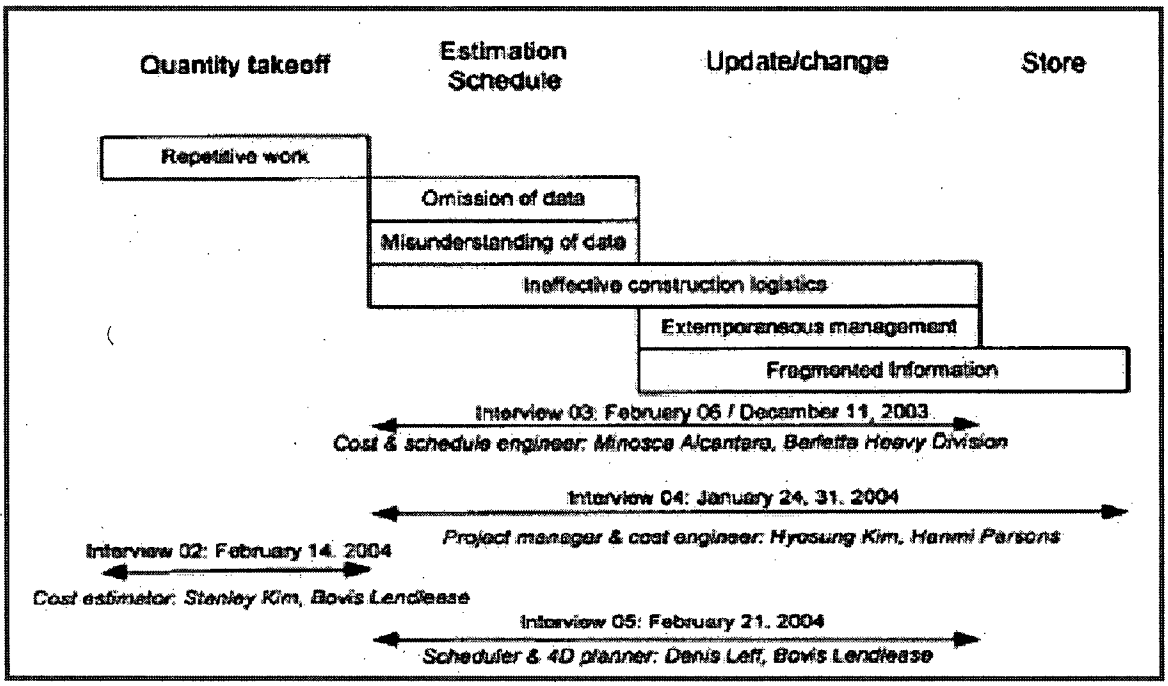


Figure 3: Interview Summary, Song (2004)

In the Architecture, Engineering and Construction industries (AEC), computer visualization usage can cover the whole lifecycle of a product from presentation of initial concepts to the final stages of production and can also extend to maintenance issues. Three dimensional

"Walkthroughs can be created from sketches at the very early stages of the design process. Three dimensional models can be used by design teams to communicate design intent to client and users and to compare and evaluate design options. During more advanced stages of design, three-dimensional representations can be used to check the integrity of services coordination, accessibility and maintainability. During construction, "visualization can facilitate the interpretation of design details by site operatives" (Bouchlaghem, Shang, Whyte and Ganah 2004).

At present the benefits that visualization and VR can bring to the construction industry are fully appreciated by the majority of practitioners. However, despite the continually falling costs associated with the hardware and software, there remains a big obstacle to its full usage; this is the low compatibility between Virtual Reality and the existing CAD infrastructures making its implementation costly due to the resource intensive task of creating the models.

2.4 CREATING REALISTIC 3D VISUALIZATION

The essence of 3D visualization comes from its constituents' 3D objects which are generated through 3D modeling process. Generally, this process is complex and time consuming especially for the complicated construction operations, and even considered as deterrent to visualization in some literature (Brooks 1999) or even to "3D visualization of simulated construction processes" in particular (Zhang et al. 2002) .

3D visualization models for construction operation could have all participating objects in the process from trade labors and equipments, to materials and construction site. The necessity of Computer-Aided Design for modeling these involved elements in simulation is inevitable. Construction operation can be visualized through using and manipulating the 3D models in virtual environment (Kamat & Martinez 2005). The more illustrative and real these models created, the more help for comprehension and analyzing the construction process can be achieved.

In order to create a 3D visualization models, it is not necessary to model all objects from scratch. Although some complicated operations or methods of construction impose creating most of the objects like the experience with this project, many 3D objects in various formats can be easily found through online libraries and the price range is depend on the quality and complexity of the models, or even libraries of the software such as Autodesk Architectural Desktop can be utilized. Also, the CAD models from the design stage of the previous construction projects can help the visualization process (Brooks 1999).

There has been a controversy over the necessary degree of realism among those who involved in the process of visualization. The visualization models reality, range from 2D animation to detailed 3D life like virtual world. The choice between these boundaries is a matter of stakeholders' opinion which has been enhanced due to the advancement in computer technologies, computer games and animation movies (Kamat and Martinez 2004). Farr and Sisti (1994) argued that engineers must provide a realistic illustration in the form of visualization animation as a communication tool that can depict real world processes. Also, Roher (2000) believes that the degree of realism must reach a level that any other clarifications such as text do not necessary for the visualization model.

Various levels of detail can be implemented in visualization process to represent the construction operations in many ways in order to depict the required realism in the simulation model, provide significant insight to the project details and established a credible model for better understanding of the project.

The choice of degree of realism can be limited by, available computer resources in terms of software and hardware technologies, specialized human resources and time constraints. At the end of visualization procedure, the product must have enough realism to convey the necessary information about the construction operation to project participants, and help the project planners with decision making (Kamat and Martinez 2001 & 2005).

In addition to the simulation and visualization systems that were mentioned before, also some manufacturing simulation systems display real-time 3D animation of modeled operations during simulation runs. Examples of such systems include Delmia's Quest

(Delmia, 2000), and AutoSimulations' AutoMod (AutoSimulations, 2000). These systems have modeling constructs and built-in 3D templates of common manufacturing environment and equipments that enable users to simulate and visualize most manufacturing operations (Donald, 1998).

In recent years, given the current state of affairs, Dr. Kamat and his colleagues experienced the need for a generic 3D visualization system that would be capable of realistically depicting modeled construction operations as well as the evolving construction products in 3D virtual space.

He conducted a considerable amount of research in the area of construction visualization to the extent that he can be consider as one of the leading researchers in this area. He and his research team, developed many software for realistically visualize the construction operations from different perspective and viewpoints. As an illustration, he produced dynamic 3D visualization of Fluid construction materials (Kamat and Martinez 2003), 3D animation of multiply articulated construction equipment (Kamat and Martinez 2005), and large scale dynamic terrain (Kamat and Martinez 2005). Also, he introduced twelve sets of software in his webpage for the area of construction visualization (pathfinder.engin.umich.edu/software.htm).

Intricate construction operations can benefit from 3D visualization in different stages from planning to design, due to the fact that conventional methods are ineffective and sometimes obsolete. Although utilizing 3D visualization in real projects is not common, they definitely assist in providing "valuable insight into the subtleties of construction operations" (Kamat and Martinez 2001).

2.5 Landscape Visualization

Sheppard et al. (2004) defined Landscape visualizations as "pictures of real places seen in perspective that show visible or non-visible features or recognizable landscapes in the future, the present, or the past". Further, pictures of objects, conditions, processes, or places that can be used to assist the project participants to comprehend the important characteristics of construction landscape by representing its appearance in virtual world. (Lewis, Sheppard, and Sutherland, 2004).

This type of visualization is rather new compare to the other aspects of 3D visualization. In order to simulate the landscape features and represent possible changes that might happen during construction operations, landscape visualization has been utilized to provide better understanding for decision makers and stakeholders especially when the operations taking place in environmentally important areas.

Over the past 30 years, the improved capabilities of computer hardware and software have allowed users to simulate and visualize natural complex forms and phenomena such as plant growth and the effects of changes in atmospheric conditions and light (Ervin and Hasbrouck, 1999).

There are commercial visualization systems such as Visual Nature Studio, World Construction Set, Bryce, and VistaPro etc. which produce realistic terrain images. McGaughey (1998) and Muhar (2001) reviewed the features of these systems in landscape visualization. Many researchers have developed algorithms for digital plant modeling (Oppenheimer, 1986; De Reffye et al., 1988, 1991; Prusinkiewicz et al., 1988), and three-dimensional (3D) digital plant modeling systems have been used to develop forest landscape visualization systems such as the AMAP system (De Reffye et al., 1988; Perrin et al., 2001), the Vantage Point system (Fridley et al., 1991; Bergen et al., 1998), and the Smart Forest (Orland et al., 1994; Orland, 1997).

These 3D visualization systems place individual trees on a digital terrain model (DTM) via a graphic user interface (GUI), and the images they render have nearly reached the level of photographic realism. Accordingly, the digital plant modeling techniques of these systems can be used to render forest landscapes accurately (Honjo and Lim, 2002).

While these 3D visualization systems are highly realistic, they have not yet achieved sufficient speed in modeling to allow users to use the visualization as a decision support tool (Orland et al., 1994).

In many presentations using these systems, static images or animations generated using a series of static images are mainly used (Bergen et al., 1998; Bishop, 2001; Perrin et al., 2001). In recent years, Honjo and Lim (2001) developed a system for real-time rendering of landscapes using virtual reality modeling language (VRML). With their system, actual gardens with thousands of plants could be visualized in real-time in walk-through simulations on a personal computer.

Many of the landscape visualization techniques have been available in some form for 20–30 years. Recent advances in computing technology and its application to resource management have made visualization more common in certain professional contexts (e.g., landscape architecture and regional planning).

Over the last 25 years, universities and researchers have conducted various studies into the value and effectiveness of landscape visualization in land planning and resource management (Wood 1972; Daniel and Boster 1976; Appleyard 1977; Sheppard 1982; Kroh and Gimblett 1992; Perkins 1992; Pitt and Nassauer 1992; Oh 1994; Bergen *et al.* 1995; Lewis 2000; Tress and Tress 2003). In general, this fact that landscape visualizations can fundamentally improve the public's access to information and understanding of projects are mentioned by both the research literature and practical experience (Lewis, Sheppard, and Sutherland, 2004).

Michael Zajac (1998) believed that 3D models can be "texture-mapped" with scanned images for more realism. In industrial and entertainment applications this type of 3D visualization is well developed. Advanced photo software and powerful special purpose 3D display hardware is available.

Two challenges exist for using 3D modeling in landscape visualization: first extreme complexity of realistic landscape scene and second is that even in the best case, a 3D model is "an abstraction or reconstruction of the real world, not a description of it" (Zajac 1998).

Landscape visualization applications are generally workstation-based computer programs in recent years. Ground models, terrain represented by a digital terrain model (DTM), forest stands, and generic line information representing roads, harvest unit boundaries, can be displayed by Landscape modeling packages (Lewis, Sheppard, and Sutherland, 2004).

In the table 1, the range of visualization types commonly used by environmental planners and resource managers are represented (Visualization credit: John Lewis, Collaborative for Advanced Landscape Planning, University of British Columbia, Vancouver, B.C.)

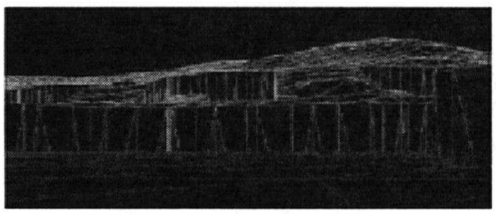
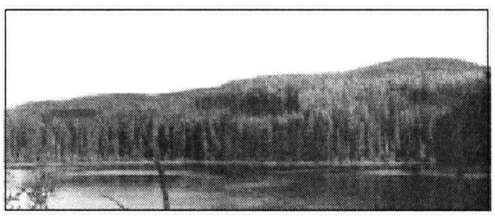
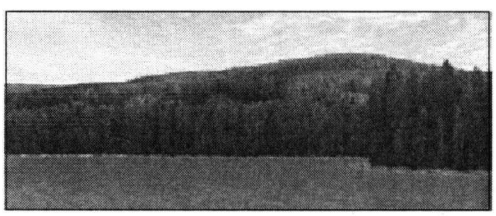
Visualization type	Technique description	Software required	Advantages/disadvantages
 WIREFRAME	Geographic Information System (GIS) or Computer-aided Design (CAD) software mathematically interpolates a continuous lattice from contour vertices or spot elevation data.	AutoCAD®, MicroStation®, or any GIS software (e.g., ArcView®, ArcInfo®, or ArcGIS®)	*Advantages:* Easy to produce for anyone with a moderate to high level of training in GIS and (or) CAD. *Disadvantages:* Very low realism; difficult to translate into a clear mental image of how the landscape will be affected by the alterations.
 PHOTOMONTAGE	Simulated disturbances are manually "painted" onto a site photo using standard photo-retouching software. The "artists" will often drape a wireframe image (see above) to aid in siting and sizing the proposed disturbance.	AutoCAD or MicroStation and Adobe Photoshop®	*Advantages:* High realism; high degree of credibility and believability by the public and decision makers. *Disadvantages:* Questionable accuracy; relies extensively on artistic judgement of the simulation preparer.
 SURFACE MODEL	See discussion, "How Landscape Visualization Works."	World Construction Set and any GIS software	*Advantages:* High photo-realism and accuracy; assuming good base data, very credible and defensible. *Disadvantages:* Time consuming to produce; requires a high level of training and experience.

Table 1: The range of visualization types commonly used by environmental planners and resource managers. (Visualization credit: John Lewis, Collaborative for Advanced Landscape Planning, University of British Columbia, Vancouver, B.C.)

Although landscape visualization has been used in many fields so far and the utilization spectrum is still growing, there are few standards for providing assistance to the users. With respect to potential benefits and limitations of landscape visualization applications, using these tools must be lead through appropriate ways (Lewis, Sheppard, and Sutherland, 2004).

Due to extreme advancement of computer technologies, three-dimensional visualization for landscaping as well as other aspects of visualization is no longer limited to research projects; it is safe to say that these tools and applications are now applicable in every day planning project work (Muhar 2001).

2.6 4D Modeling of Construction Projects

Four-dimensional CAD (3D plus time) enables project participants and clients, irrespective of their level of construction knowledge, to understand spatial constraints and explore design and construction alternatives before construction starts. It enhances the contribution between the knowledge and experience of the designers and the constructors (Song 2004).

Four-dimensional CAD developed by CIFE (Centre for Integrated Facility Engineering) at Stanford University. It visually delivers sequence of a building construction by animated 3D building model correspond to the schedule and construction sequence. 4D CAD technology allows designers and builders to represent their view of the project in one common and sharable model. Currently, various commercial applications are being used in the construction industry. Four-dimensional CAD is also being broadly applied in other fields of research, such a geodynamic or seismic visualization, etc.

In order to visualize in 4D, a 3D CAD tool (e.g. AutoCAD, Microstation, etc), a project scheduling tool (e.g. Primavera or Microsoft Project, etc), and a 4D simulation tool that is capable of integrating both 3D graphics and schedules are necessary.

During the past decade, previous research efforts have been made towards advanced four-dimensional (4D) planning models by integrating three-dimensional (3D) visualization with the time attribute. Retik et al. (1990) studied the feasibility of using computer graphics in partnership with construction scheduling and explored the required functions. Zhang (1996) reported on a 3D graphical construction model. Williams (1996) designed a demand-driven 4D model for the generation of a graphical construction plan on the basis of simulation, visualization, and communication. Collier and Fischer (1996) demonstrated visual-based 4D modeling and scheduling in a case study of the San Mateo County Hospital. McKinney et al. (1996) proposed a four-dimensional computer-aided design (4D-CAD) tool with visual and communicative functions to facilitate the design process. Adjei-Kumi and Retik (1997) applied the concept of virtual reality to visualize the construction plan using a library-based 4D model. McKinney et al. (1998) demonstrated the capability of 4D-CAD models to identify construction problems prior to their actual occurrence. McKinney and Fischer (1998) studied the effectiveness of a hybrid 4D applications using the contemporary software Primavera, AutoCAD, Jacobus Simulation Toolkit, and Walkthru. Zhang et al. (2000) developed a 3D visualization model with schedule data at the level of construction components. Kamat and Martinez (2001) presented a 3D visualization model depicting the entire process of a typical construction activity.

The 4D CAD modeling approach might be able to detect some scheduling error in the construction of a building (Griffis and Sturts, 2000). However, current 4D CAD systems are not able to cope with rapid changing of information characteristic of construction sites (Barret 2000). Therefore Griffis and Sturts (2000) discussed the desperate need for developing a 4D CAD system for schedule evaluation and control that reflects construction's dynamic conditions and performance.

O'Brien (2000) proposes 5D CAD, asserting the need for a new model-based system that can, by using an additional dimension, express the complex interactions among, cost, resource, and schedule, or cost and resource performance. Barret (2000) emphasizes the need for "nD CAD" that can be applied flexibly to project performance, since the current 4D CAD become useless when there is a change of information during construction. However, no study on 3D model based system has yet proposed a clear solution (Song 2004).

Recently, a prototype 4D visualization model has been developed and implemented by Chau, Anson, and Zhang (2004) with a view to overcoming problems incurred in conventional construction planning methods and in incorporating practical site management features. This 4D visualization model, which links the 3D geometrical model with scheduling data, comprises the activity schedule, associated allocation of resources, and layout of site facilities at any projected instant.

Song (2004) summarized the 4D CAD research and development groups in a table (Table2).

Institution & Project	*URL*
Stanford Univ. 4D CAD	http://www.stanford.edu/group/4D
OSCON project	http://www.salford.ac.uk/iti/att/oscon.html
SPACE project	http://www.surveying.salford.ac.uk/aic/space.htm
Increasing Productivity by Utilizing IT	http://www.sbi.se/canada.htm
Bechtel Aviation Services	http://www.bechtel.com/aviation/articlehome.html
Virtual Reality in the CCIT	http://helios.bre.ac.uk/ccit/info/vr/index.html
Georgia Tech, Interactive Visualizer	http://www.ce.gatech.edu/research/projects/computer/IV/iv.html
Civil-Site Planning & Roadway Design	http://www.eaglepoint.com/civil
CSA, Inc.	http://www.csaatl.com
Eurostep	http://www.eurostep.com
Purdue 4D	http://www.ecn.purdue.edu/ECT/other/4D
Virtual STEP	http://www.virtualstep.com/index.html
VTT-4D	http://cic.vtt.fi/4D/index.htm
Bently System. 4D CAD Schedule Simulator	http://www.bently.com
Solibri	http://www.solibri.com
Elcon System	http://www.el-con.co.kr/elcon/

Table 2: 4D Research and Development (Song 2004)

Based on a case study that used 4D CAD modeling on an actual development, a CIFE research team at Stanford University come to the following conclusion about 4D modeling (Collier & Fischer 1995):

> "The 4D model gives more explicit explanation of construction operations, enabling the client and others to play a more informed role in design and construction. The major benefit of this will be more satisfied customers who face fewer unexpected surprises during construction, feel more a part of the process, appreciate the complexity and danger of the work, feel that the contractor is taking an active role in helping them meet their goals, and receive more construction value through a higher level of efficiency".

Koo and Fischer (2000) argued that, 4D tools should include bar charts, component lists, and annotation tools in their graphical user interface. They also mentioned that, automating schedule data preparation and 4D model generation in the design stages of a project can expedite 4D model development and use. Users need to be able to generate 4D models at multiple levels of detail and generate and evaluate alternative scenarios rapidly.

There are many potential benefits of a 4D visualization system, including facilitating site planning and management, predicting the occurrence of any potential site problems, and streamlining the site management practices.

Moreover, the advancements in computing technology have assisted in this work, resulting in a user-friendly, comprehensive, and integrated site management tool. It is believed that 4D visualization will have strong potential in construction planning and management processes (Chau, Anson, Zhang, 2004).

2.7 State-of-the-Art 3D and 4D Software

In the current world of technology due to immense development in software and hardware technology, the opportunity to provide various "domain specific" application is available in different fields There are urgent and necessary needs on higher degree of assistance from computer in order to gain efficient planning and management regarding the ever increasing complexity of the projects (Chau, Anson, Zhang, 2004).

State-of-the-Art construction simulation tools permit the modeling of complex construction operation at any level of detail (Martinez and Ioannou 1999). By using these tools in various aspects of construction operation and activities in advance of the actual construction project, convenient comprehension and understanding can be provided through these virtual models (Kamat 2004).

In this section it will be tried to overview the 3D, 4D and landscaping software in the area of construction visualization.

2.7.1 3D Modeling

Construction companies are increasingly utilizing Three-Dimensional modeling and visualization software with the aim of representing their construction products and communicating design, planning and decision making information to their clients, to suppliers/manufacturers and public. Heuristic decision-making and planning stages of construction, with respect to 3D software seem to be under-researched, but on the hand it is safe to say that design management have been explored extensively. The reasons come from the human side of the process which is complicated and less straightforward to map).

The opportunity for companies to apply 3D models in their projects has been provided by advances in three-dimensional (3D) computer-aided design (CAD) technologies during past two decades. On the other hand, without the ability to represent the exact status of a project during a specific period of time, 3D models can not help a lot in progress control by themselves (Chau et. al, 2004).

The 3D software world can be generally divided into two basic groups; the first one includes the commercial sets of software while the second one contains academic efforts in this area. By considering the extreme domain of 3D software usage which incorporates several various fields in the current world of science and technology, it is easy to conclude that there are hundreds of 3D software can be found nowadays. On November 2005 U.S. Army Topographic Engineering Center conducted a survey for available 3D software commercially available. The objective of the software survey is to provide an overview of the many potential commercial solutions available for 3-D terrain visualization applications, but it included 3D software as well. They found over 700 different 3D sets of software, which included very popular and famous software like Autodesk Architectural Desktop and 3D Studio Max to very obscure and strange sets of software.

Also, in terms of academic work, there have been a lot of efforts in the area of 3D software and system development. Vaugn (1996) emphasized the use of 3D and rather 4D system for project planning and execution. For companies uncomfortable with 3D systems one maxim holds "If you can't build it in 3D, you can't build it in the field" (Vaughn, 1996).Ito (1995) described 3D graphical simulation system that can be used for temporary facility planning using object oriented building model. This model has user-friendly interface and support simulation, visualization and documentation of facility system.

Dharwadkar (1994) used 3D CAD modeling of mobile cranes and simulated the operation. Intergraph's MicroStation was used to generate 3D drawing i.e. geometry of the crane and then its operation was simulated using Bechtel's WalkThru animation package.

Raynar and Smith (1994) combined vision technology with 3D CAD to produce as built drawings. Technique is simply to take 2D pictures of the construction project with cameras fitted at pre-determined points. The 2D image from cameras using Global Lab image 2.0, software is used as input into computer where software converts the photographic image into 3D image. The image thus obtained is compared electronically with the 3D drawing generated for the project. Thus building accurate structures as drawn on drawings has become possible using these techniques. Dharwadkar (1996) highlighted an object-oriented system known as JSpace. It is a system developed by Jacobus Technology Inc. and is used for creating sophisticated applications for AEC industry.

Kunigahalli (1997) used 3D modeling for Computer-Integrated Construction of RC structures.

Kamat (2000) capitalized on a computer graphics technology based on the concept of the "Scene Graph" to design and implement a general purpose 3D Visualization system that is simulation and CAD-Software independent. This system, the "Dynamic Construction Visualizer", enables realistic visualization of modeled construction operations and the resulting products in 3D and can be in conjunction with wide variety of simulation tools.

Singh (2002) used node structure of the rectangle adjacency graph (RAG) to give complete representation of the 3D representation scheme. This modeling scheme can be directly used to develop computer-aided design/ computer-aided construction (CAD/CAC) systems for RC structures (RC structures with rectangular/ square columns with one or two way slab). The geometric data structure provided by him to support the modeling scheme is quite efficient.

In recent years, Dr. Kamat and his colleagues have been very active in the area of 3D visualization. They developed many software and systems that can be useful in construction visualization. In his webpage, Dr. Kamat summarizes their 12 different sets of software in the area of 3D visualization.

As an illustration, Kamat and Martinez (2003) extended the state-of-the-art in scientific simulation-driven 3D construction process visualization. They presented a tool, ParticleWorks that engineers can use to visualize construction processes involving "fuzzy," unstructured, materials that are generally capable of flowing. Common processes that involve such fuzzy materials include placing concrete, dumping dirt, shotcreting, sandblasting, dewatering, water distribution, and inserting slurry. They capitalized on a classical computer graphics concept called particle systems to design simple, parametric text methods to represent arbitrary dynamic volumes of fuzzy construction materials in 3D virtual construction environments. Engineers can use these methods to instrument external authoring interfaces (e.g. simulation models) to automatically generate dynamic visualizations of any modeled operations that handle and process such fuzzy materials.

Also, in his PhD thesis, Dr.Kamat (2003) developed a system, VITASCOPE, which provides essential capabilities that enable it to animate simulated construction operation in smooth, continuous, dynamic, 3D virtual worlds. VITASCOPE is a simple, parametric-text animation description language that is meant to be written out end-user programmable software such as discrete-event simulation tools. Sequential instructions written in this language allow a computer to create a 3D virtual world that is accurate in time, space and appearance; and that shows people, machines, and materials interacting as they build constructed facilities.

2.7.2 Landscaping Modeling

Interactive dynamic characteristics of environment which come from various aspects of the landscape elements such as temporal, spatial and scale dynamics, and their interactions, make the environment-related visualization complicated. Environmental modelers have been trying to address and solve these problems by making different models, use different methods and techniques (Xia, 2003).

Environmental modeling has been expanded separately for a long time. People use all kinds of landscape visualization techniques to model different systems for the purposes of their field of the study. There is enormous research and application done and being continuously developed such as CAD, GIS, Geometric Modeling, etc. (Ervin and Hasbrouck, 2001). Methods and techniques vary from each other.

Ervin and Hasbrouck use a synthetic approach to provide a broad introduction of these techniques used in making digital models and visualization of the primary components in landscape systems. They claim that scientists and planners consider modeling as the way to understand the landscapes and landscape processes, explore hypotheses, and make quantitative measurements. These tasks can be interlinked by many aspects of the environment problems and need the support from many computerized models which are different in functions and methods (Ervin and Hasbrouck, 2001).

After having reviewed the existing landscape modeling and visualization techniques, Xia (2003) summarizes that there are nine major categories for dynamic landscape modeling divided by two aspects: the data of landscape elements: singular or isolated, interactive, or evolutionary dynamics; and the computer visualization techniques: static, animation, or interactive between the human and the computer tool. He categorized some application examples into the following table (Table 3).

Data / Visualization	Singular / Isolated	Interactive Relationship	Evolutionary Process
Static Representation	Image/Photo CAD	Diagram Static GIS	Hydrologic Chart
Animation Representation	Power Design Animation/walk-through	Tree Growth	Cellular Automata
Interactive Representation	VRML	Smart Forest	Swarm

Table 3: Categorizing the existing techniques for dynamic landscape modeling and visualization, Xia (2003).

On the other hand, Sheppard et al (2004) summarized the resources that are required to implement GIS and/or landscape visualization in a table. Part of this table is presented below (Table 4).

	Level 1 - Third Party	Level 2 - Basic	Level 3 - Advanced
Specialized In-House Staff Required	0	1+	1-3
Training Requirements	Simulation Standards (No Formal Training)	Simulation Standards Intermediate Visualization (1/2 to 1 day Course)	Simulation Standards Advanced Visualization Methods (4 to 5 day Course)
Software	N/A	ArcView w. 3D Analyst AutoCAD Adob Photoshop	ArcGIS Adob Photoshop Visual Nature Studio**
Completion Time*	<1 Day	~ 1-2 Weeks	3-4 Month
****Estimated length of time to complete implementation***			
***** Level three implementation is based largely on Visual Nature Studio with limited use of Adobe Photoshop.***			

Table 4: Resource Summary of GIS and/or Landscape Visualization. Sheppard et al (2004)

In the following table (Table 5), by using The Collaborative for Advanced Landscape Planning (CALP) website, the most important sets of landscaping software along with their related website are presented.

Xiu (2003) believes that the goal of dynamic landscape visualization is a combination of 'how can computation landscape visualization techniques provide the animated and interactive interface', and 'how can we understand and capture the dynamics of landscape system'?

In general, environmental computerized visualization techniques are intended to provide sufficient support to allow the landscape designers and planners, as well as those who use this type of visualization in their projects, to achieve these goals more efficiently. With the rapid advancement of the visualization techniques and methods, there is a fundamental but essential need for comprehensive and integrated computational support for the development, evaluation, and application of environment modeling and visualization of broad range phenomena (Goodchild, 1996).

Category	Software Name	Software Website
3D Landscape Modelers	Bryce 5	www.corel.com
	Natural Scene Designer	www.naturalgfx.com
	Vue D'esprit	www.e-onsoftware.com
	World Builder	www.digi-element.com
2D/3D Hybrid Landscape Modelers	Enfor - Visual Terrain Planner	www.fore-tech.com
	Envision	http://faculty.washington.edu/mcgoy
	Genesis II	www.geomantics.com
	LMS/SVS	http://silvae.cfr.washington.edu/lms/lms.html
	SmartForest	www.imlab.psu.edu/smartforest
	Terragen	http://www.planetside.co.uk
	Virtual Forest	www.innovativegis.com
	World Construction Set	www.3dnature.com
	Visual Nature Studio	www.3dnature.com
Image Draping Terrain Modelers	ArcView 3D Analyst	www.esri.com
	Landform C3	www.landform.com
	Truflite	www.truflite.com
	Terrex Terra Vista	www.terrex.com
Photogrammetry 3D Modelers	Canoma	www.eovia.com
	Photomodeler	www.photomodeler.com
	RealViz Image Modeler	www.realviz.com
Tree Builders	CIRAD-AMAP's Genesis	www.cirad.fr
	Digimation Tree Factory	www.digimation.com
	Onyx Tree Professional	www.onyx.com
	X-Frog	www.greenworks.de
QuickTime VR Authoring Tools	Apple QuickTime VR Authoring Studio	www.apple.com
	Bryce 5	www.corel.com
High End/Non-PC Based Modelers	Alias/Wavefront	www.alias.com/eng/index.shtm
	Centric Software (Coryphaeus)	www.centricsoftware.com
	MultiGen	www.multigen.com
	Polytrim	www.clr.utoronto.ca/polytrim.html
	Sense8 Software	-

Table 5: Landscaping Software

2.7.3 4D Modeling

It is almost two decades since the outset of 4D CAD and in spite of its widely acclaimed advantages; it is still in the incubation stage mainly within academia. 4D CAD focuses on the visualization of the constructed product over the period of its construction by animating the transformation of space over time. This is accomplished by a 3D CAD model representing the complete product design and a construction schedule (McKinney et al. 1996).

There are few commercially available 4D CAD tools on the market. The following table (Table 6) summarized these tools along with the name of the production company and their website.

Software	*Company*	*Website*
NavisWorks Jet Stream	NavisWorks Ltd.	www.navisworks.com
Project 4D	Common Point	www.commonpointinc.com
Schedule Simulator	Bently Systems	www.bently.com
4D Builder	VirtualSTEP	www.virtualstep.com
fourDscape	BALFOUR Technologies	www.bal4.com
The Visual Project Scheduler	Visual Engineering	www.visual-engineering.com

Table 6: 4D Software and Service Providers

Retik et al. (1990) discussed the possible use of computer graphics as a scheduling tool. Williams (1996) generated a 4D movie or animation film of a series of activity queues to help understand the construction plan realistically. He emphasized on three things visualization, simulation and communication in his 4D planner. Building blocks can be seen visually and component visibility, transparency, render mode, and color can be controlled. Collier and Fischer (1996) linked layers in a 3D-CAD model to construction activities in a construction project. McKinney et al. (1996) presented a prototype 4D tool to allow planners to manually generate CAD, schedule, and 4D content. Adjei-Kumi and Retik (1997) presented a library-based 4D model for planning and visualizing the construction plan. McKinney and Fischer (1998) gave an overview on generating, evaluating and visualizing construction schedules with CAD tools. Liston et al. (1998) developed a 4D-CAD visual decision support tool for construction planners, with visual cues for quick identification of problem areas. Staub-French et al. (1999) illustrated that 4D simulation was better for construction planning than Gantt charts or CPM schedules.

Koo and Fischer (2000) showed that 4D models are effective in evaluating the executability of a construction schedule and highlighted the need for improvements to 4D tools. Kamat and Martinez (2001) described a system to enable spatially and chronologically accurate 3D visualization of specific construction operations. Kamat and Martinez (2002) capitalized on a computer graphics technology based on the concept of the scene graph. Chau et al. (2003) implemented a 4D management approach to construction planning and site space utilization. Dawood et al. (2003) reported on the development of an integrated database for 4D construction process simulation.

Construction management will be highly affected by 4D CAD technology which has strong potential for construction industry. Adding components that relate to construction activities such as scaffolding to the 4D models can be considered as an extension in this technology and can be done by feasible research direction. Further, by merging 4D CAD into AEC working environment by using web-based collaborative system other capabilities of 4D technology can be revealed. Moreover, with the aim of locating potential areas where problems may occur, a suitable approach to assess construction plans can be provided (Chau, Ansona and Zhang, 2004).

2.8 CONCLUSIONS

In order to provide a unique comprehension of construction activities and represent different plans and designs for helping in the better decision making process, 4D visualization methods can be utilized.

During conceptual design, visualization tools can help designers work collaboratively and communicate ideas more efficiently. In housing development, site layout models can be used as a marketing tool with clients or for planning consultations with planners, at the same time it can improve the way house type designs are developed by design teams.

Visualization applications are becoming more readily available and accessible to construction professionals due to the continuously decreasing cost of software and hardware. Some leading construction firms have invested large resources for the use of visualization in house realizing its business benefits. Some of these companies are using advanced tools for the creation of walkthrough models of new developments to communicate concepts to clients, or to check the integrity of designs in terms of clash detection between the services and the structure.

Implementation problems of these new technologies have always been the main barrier in adopting them, however while in the past the main problem was cost, it is now more organizational and human issues that stand in the way of taking full advantage of the benefits that can be realized. This is now being seen as the next challenge in this area of research where both academics and practitioners are realizing that successful adoption of new technologies depends on careful consideration of organizational and business issues (Bouchlaghem et. al. 2004).

Visualization tools provide engineers with more understanding of and insight into project information. Visual simulation of facility design would provide an ideal tool for exploring, analyzing, and evaluating different design alternatives, and for supporting effective communication and collaboration among project team members.

CHAPTER 3

CASE STUDY OVERVIEW: THE GATEWAY BRIDGE PROJECT

3.1 INTRODUCTION

The Gateway Program was established by the Province of British Columbia, because of the population growth over the past two decades, growing regional congestion, and to improve the movement of people, goods and transit throughout Greater Vancouver (www.gatewayprogram.bc.ca). Since the 1980s, no considerable improvements have been made for Greater Vancouver's road network, and transportation was ranked as the first problem by residents in the region. Also, regarding the economic growth of this area and the fact that this region has become an important gateway for international trade, the necessity for regional transportation infrastructure, such as highways, Sky Train and intercity buses was obvious.

The Gateway Program was established to solve the aforementioned problems and enhance the transportation infrastructure. This $3.9 billion project is going to be performed over the next 10 years, and includes transit and roads, Bus Service, Rapid Transit, Roads and Bridges, Sea Bus, U-Pass, Bikes and Gateway Road and Bridge Projects. The Gateway Program has three main components: The Port Mann /Highway 1 Project, The North Fraser Perimeter Road Project and The South Fraser Perimeter Road Project.

Our research focuses on part of The South Fraser Perimeter Road Project (SFPR) in the form of a case study, which includes a bridge and part of the connection road. The next section describes the scope of our research in more detail.

3.2 PROJECT OVERVIEW

The Gateway Program website introduced The South Fraser Perimeter Road Project as "a primarily new four-lane, 80 km route along the south side of the Fraser River extending from Deltaport Way in southwest Delta to 176th Street and the Golden Ears Bridge connector road in Surrey/Langley"(www.gatewayprogram.bc.ca).This part of the Gateway Project will operate as an efficient and important route to serve the port facilities, rail yards and industrial areas along this key economic corridor such as the Vancouver Port Authority's Deltaport expansion, the Fraser River Port Authority's Fraser Surrey Docks, CN Intermodal yard, Canada/U.S. border crossings, the Tsawwassen ferry terminal to Vancouver Island, and numerous industrial areas.

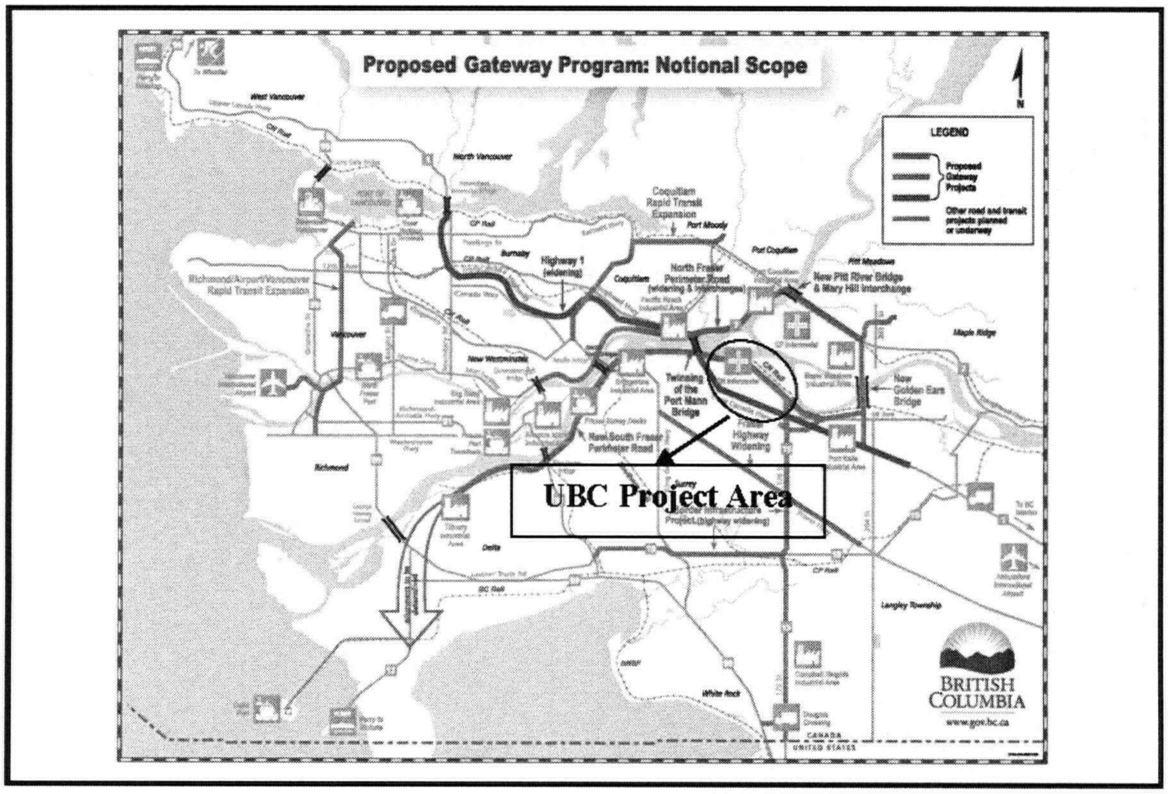


Figure 4: Proposed Gateway Program: National Scope(www.gatewayprogram.bc.ca)

Also, as a paramount transportation corridor SFPR will enhance the quality of life for residents and commuters, provide goods transportation, and decrease the volume of regional traffic and trucks on arterial and community streets with connections to Highways 1, 15, 91, 99, and 17, and the future Golden Ears Bridge.

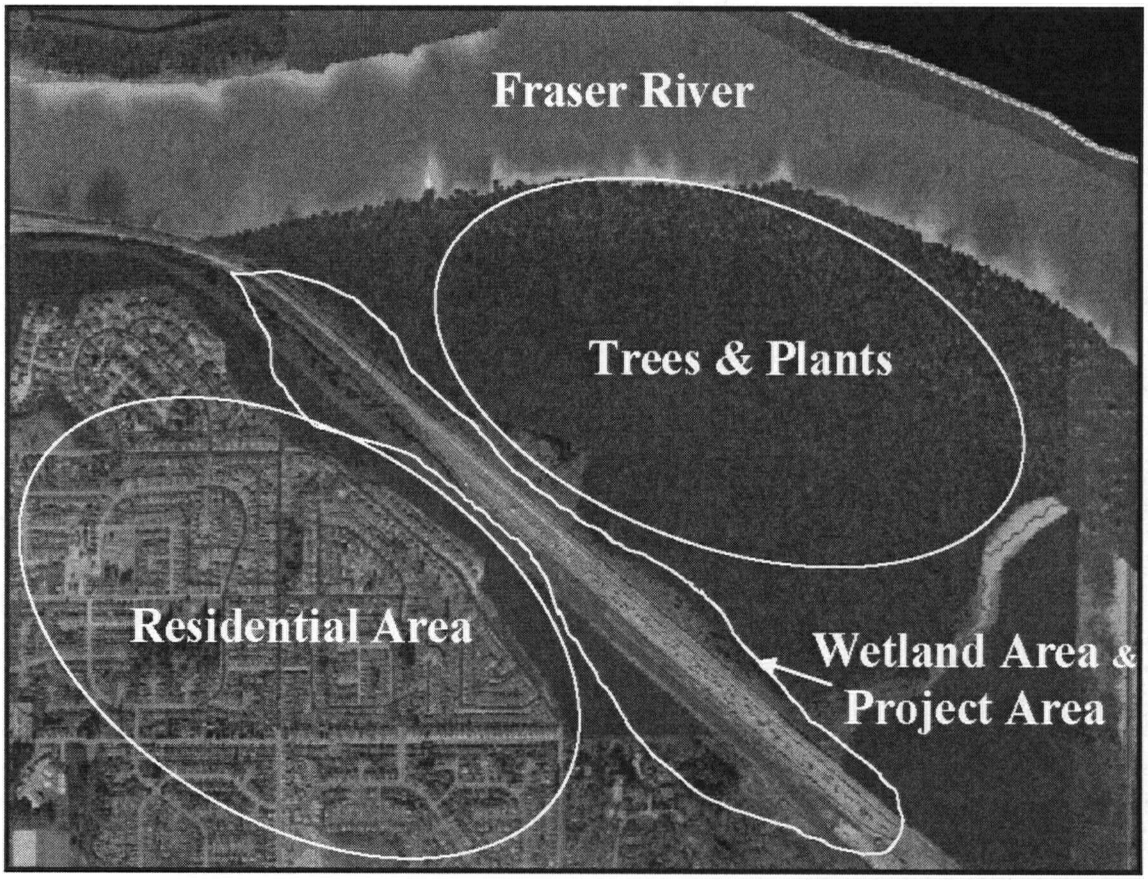


Figure 5: Satellite Picture of the UBC Project Area

The UBC project area is part of the SFPR component of the Gateway Program which included a bridge and part of the connection roads to this bridge (Figure 4). Figure 5 shows the satellite picture of the area and the surrounding environment. The general purpose of this project in the form of a case study was to represent the capabilities and features of 3D and 4D construction visualization tools for communication, and learning when applied to projects in advance of construction.

3.3 PROJECT PARTICIPANTS

The Gateway Program is administered by the Ministry of Transportation (MoT) and of British Columbia. Many consultant companies are involved in this project: Delcan, CH2M Hill, Golder Associates Ltd., Acres International Ltd., Hemmera, Envirochem Inc., E. Wolski Consulting, National Land Consulting Inc., Girard Land, Services Inc., UMA Engineering Ltd., Wakefield Acoustics Ltd., Levelton Consultants Ltd., Coast River Environmental Services Ltd., Robertson Environmental Services, Summit Environmental Consultants Ltd.

Delcan Corporation was the designer of the bridge that was the focus of our research. Delcan Corporation is a multi-disciplinary engineering firm specializing in Program and Project Management, Intelligent Transportation Systems, Information Technology, Systems Integration, Bridges and Structures, Architecture, and Civil Engineering. Delcan performs its work through a variety of avenues, including consulting, contracting, design-build projects, and private ventures (www.delcan.com).

Our research focused on a new bridge in The South Fraser Perimeter Road Project. It was conducted as part of a research assistantship and thesis project for Dr. Sheryl Staub-French as part of the University of British Columbia's Gateway Project Visualization Agreement with the BC Ministry of Transportation (MoT), which is being coordinated by Gordon Bonwick. We also worked with Delcan Corporation representative Stephen Dubreuil during the course of the project to understand the design of the bridge.

3.4 VISUALIZATION NEEDS

The Ministry of Transportation (MoT) as the administrator of all transportation infrastructures throughout the province of British Columbia (B.C) has a broad range of public relations with the residents of B.C. In recent years they have tried to enhance the representation of their projects more effectively and efficiently, when communicating with a variety of stakeholders. In order to reach this goal, they have tried to develop realistic virtual models of their projects using advanced software technology. Specifically, they tried to visually communicate the surroundings of the projects before, and after construction with as much reality as possible by using available visualization tools. As an illustration, due to many plans for construction of transportation infrastructure in the province, and the fact that all of them are involved in environmental issues as well as community matters, MoT decided to utilize the available potential in the technology to fulfill this need and provide construction process visualization.

MoT representative declared his expectations for this case study from the outset of the project. As a client of this research work, he expressed what he is looking for in terms of attributes of visual representation of the project. By showing previous visualization works which were done by professional contractors, he asked for as much realism as possible in modeling the bridge and its surrounding before, during and after the construction by using available 3D and 4D visualization tools.

Regarding the fact that SFPR project is so huge, they decided to give us part of the project which was a bridge. Because of the bridge location, environmental issues such as fish habitat area in the wetland and also landscape of some residential buildings were involved. So, this case study could provide a good example of MoT's goal to fulfill the needs to communicate construction process visually for better comprehension of the project for stakeholders.

The ultimate aim of this visualization process was to show the construction activities and its consequences to the surrounding environment in terms of visual attributes so that stakeholders who do not have any background in construction could understand the project.

3.5 RESEARCH SCOPE

With respect to the primary goal of the case study which was defined by MoT, this project represents the visualizing simulation models of construction operations in three-dimensions for part of the Gateway Program.

The research project consisted of making 3D and 4D models for 490m bridge and part of its connection road. We tried to learn how to represent the construction process for the bridge and the area before and after the construction activities as well as during the process of construction as real as possible, in order to satisfy the needs of client. Also, we tried to learn how we can increase the realism of the work to make the representation of the project more acceptable to those who do not have any construction experience and consequently meet the client expectation. Further, with the aim of showing the area and the environment around the bridge, we tried to learn how to utilize landscaping software to enhance the realism of the project surroundings as much as we could.

During the project, different approaches were considered and experienced to produce 3D and 4D models in order to communicate effectively with the stake holders of the project and reach the project goals and research objectives. We tried various approaches for interacting with different software, in order to visualize the construction process by utilizing the advancement in software and hardware technology. Various sets of software were assessed as tools for visualization process during the research. As an illustration, we used Autodesk Architectural Desktop for 3D modeling and NavisWorks Jet Stream for building the 4D model. Also, Visual Nature Studio and its plug-ins were used for landscaping of the project.

We tried to find the best way for showing the construction activities either in Macro or Micro Level, as well as surrounding environment and landscape of the area. In Macro level we tried to show the general concept of the construction method which is going to be used in building the bridge, while in Micro we focused on more detailed construction activities during the course of construction. Moreover, in landscape modeling we tried to show the changes in surrounding environment of the bridge after construction and represent the consequences to the residential buildings landscape by providing snapshots of the future view of the area.

In the next chapter, the whole visualization process for this project and different approaches to reach the research objectives will be discussed and illustrated.

CHAPTER 4

3D AND 4D MODELING OF THE GATEWAY BRIDGE PROJECT

4.1 INTRODUCTION

Construction visualizations enable the depiction of alternative construction actions and their potential consequences in a format that is understandable to a broad spectrum of stakeholders.

Our Project is part of the Gateway Program. The Gateway Program was established by the Province of British Columbia in response to the impact of growing regional congestion, and to improve the movement of people, goods and transit throughout Greater Vancouver (Figure 6).

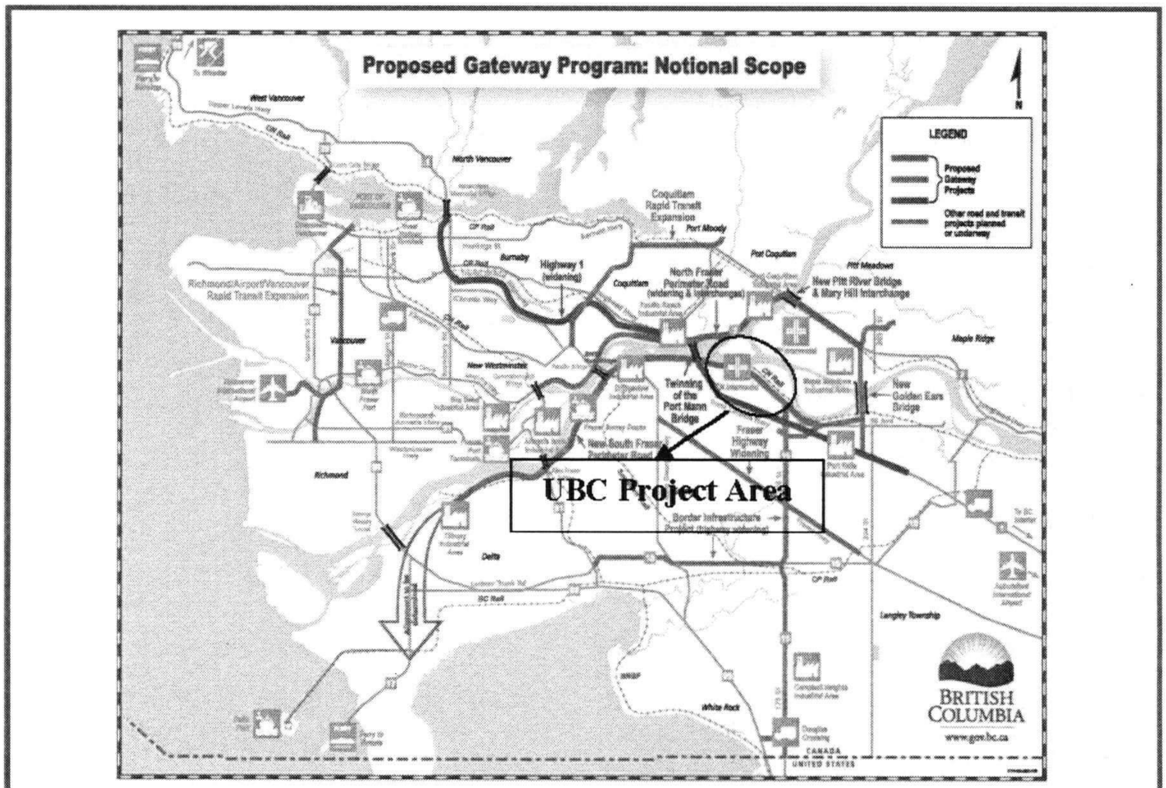


Figure 6: Proposed Gateway Program: National Scope and UBC Project Scope (www.gatewayprogram.bc.ca)

This project consisted of making 3D and 4D models (4D models combine 3D CAD models with construction activities' schedule to display the progression of construction over time) for a bridge and part of the connection road which are going to be built in the Surrey area.

The goal of the project is to reveal the benefits of 3D and 4D visualization tools in order to illustrate the situation of the construction site before, after and during the construction process. Construction visualizations are illustrations of actual places seen in perspective that represent visible or non-visible features or recognizable landscapes in the future, the present, or the past.

Generally, our process for creating visualizations consisted of making the 3D model of the bridge by using sketches of the plans, simple 2D drawings and advice from the project designer and client. Then, we exported this model to 4D software and connected it to the project schedule which represented a particular construction method. This procedure was repeated many times in order to represent the real process of construction (Figure7).

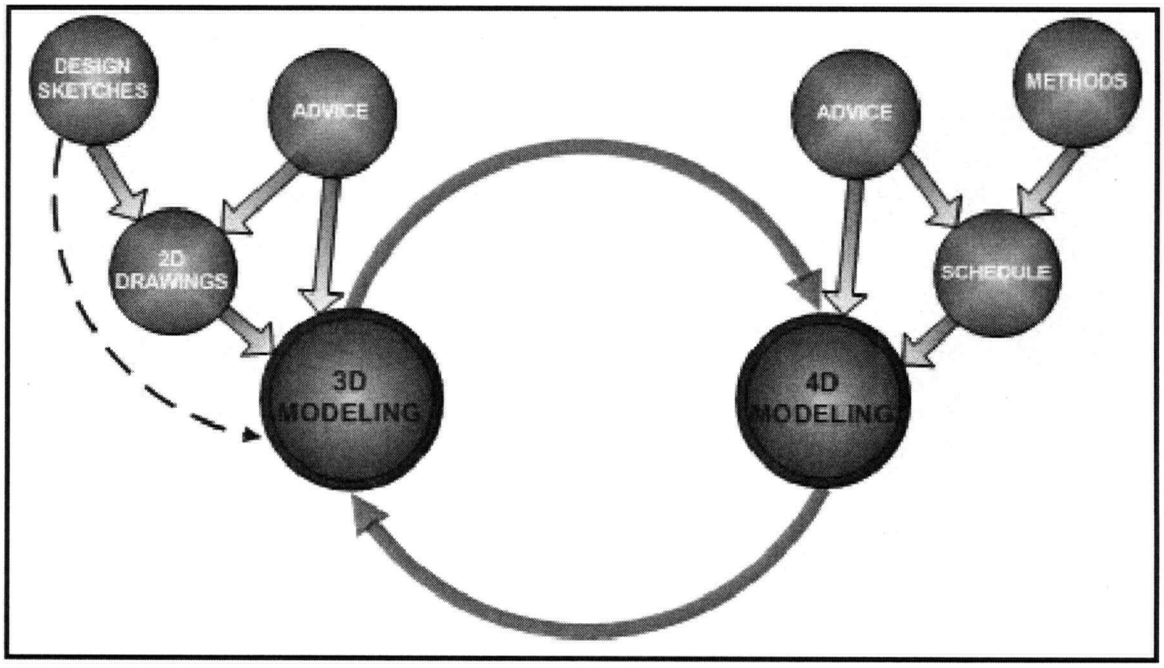


Figure 7: Process for Creating 3D & 4D Visualizations on the Gateway Project.

Then in 4D modeling we attempted to enhance the realism of the models in comparison to the traditional 4D models. We tried to make the 4D models more comprehensible. This was done by adding construction equipment and materials, and assigning materials and colors to objects.

Each 4D model consists of two main parts: 3D model and Schedule. Any changes in each of these two parts result in changing the 4D model. Generally speaking, 3D and 4D modeling has a reciprocal relationship. In this project, we had to return to the 3D model many times to change the design details, and consequently this caused changes in the 4D model. Making changes in the 4D model does not always relate to the 3D model, however, sometimes the project schedule had to be changed in order to show the realism of the process in a way that satisfies the client.

We used Autodesk Architectural Desktop (ADT) to make the 3D models, NavisWorks to build 4D models and Microsoft Project to prepare the construction schedule. Moreover, in order to enhance the visualization quality, the powerful software. Visual Nature Studio (VNS) was used for landscape visualization. The VNS project was built by importing the 3D bridge model into VNS software. An aerial photograph was draped on the terrain. Houses in the subdivision were added to the model, and a series of still images were rendered. It should mention that some other sets of software such as Microsoft Excel and Microsoft Project were used occasionally during the project, and they also will be discussed further. Figure 8 shows all of the software that has been used during this project.

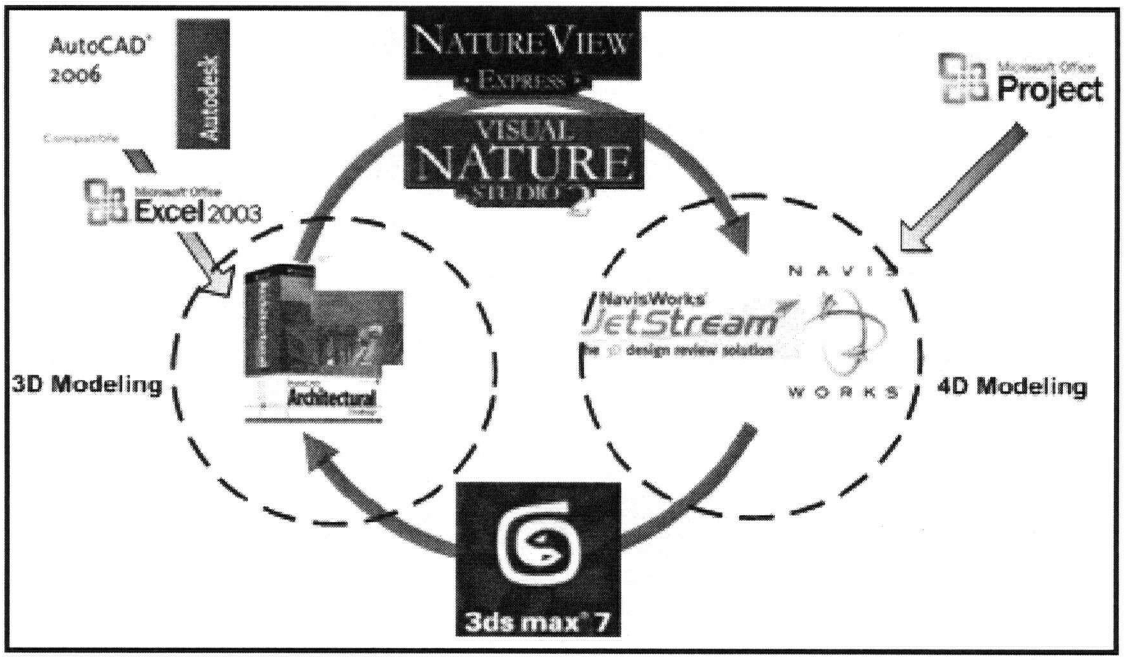


Figure 8: Software Involved in Visualization Process

This chapter illustrates the process of making the 3D and 4D models by using different approaches and methods. The decision process for finalizing each step will be reviewed. Also, software tools which were used for this project will be discussed and critiqued. Finally, issues and challenges that have been faced during the 3D and 4D modeling will be described thoroughly.

4.2 3D MODELING

Four different bridges were offered by the design company (DELCAN) at the outset of the project. In terms of piers, these models were almost the same and the difference was only in their deck segments, or in other words sectional segments. Each type of the bridge was considered for the special construction method by the design company. In other words they considered one type of the bridge for each method, and since they were not sure about the plan at that time, they offered all four types. Due to the time constraint, they agreed on the most important type which will be discussed further, and the modeling process began.

Regarding the available materials, sectional drawings of the bridge, profile and plan of the road and typical section of the road was provided in DWG format. The satellite image of the current site was also available in high and low resolution format.

Generally, three main objects were modeled: bridge, road and landscape. Each of these objects consisted of many other 3D elements that shape the whole object. The main challenging part was to integrate all of them and make one 3D model that represents the bridge and its surroundings, realistically. The other challenge was lack of detailed information and dimensions in the documents and drawings.

4.2.1 Create Path of the Bridge and Road

In order to make a 3D model of the bridge the basic need was coordination of the bridge, road and position of the structure in the road. We were provided with an image that was roughly marked and showed the area which had to be modeled (Figure 9).

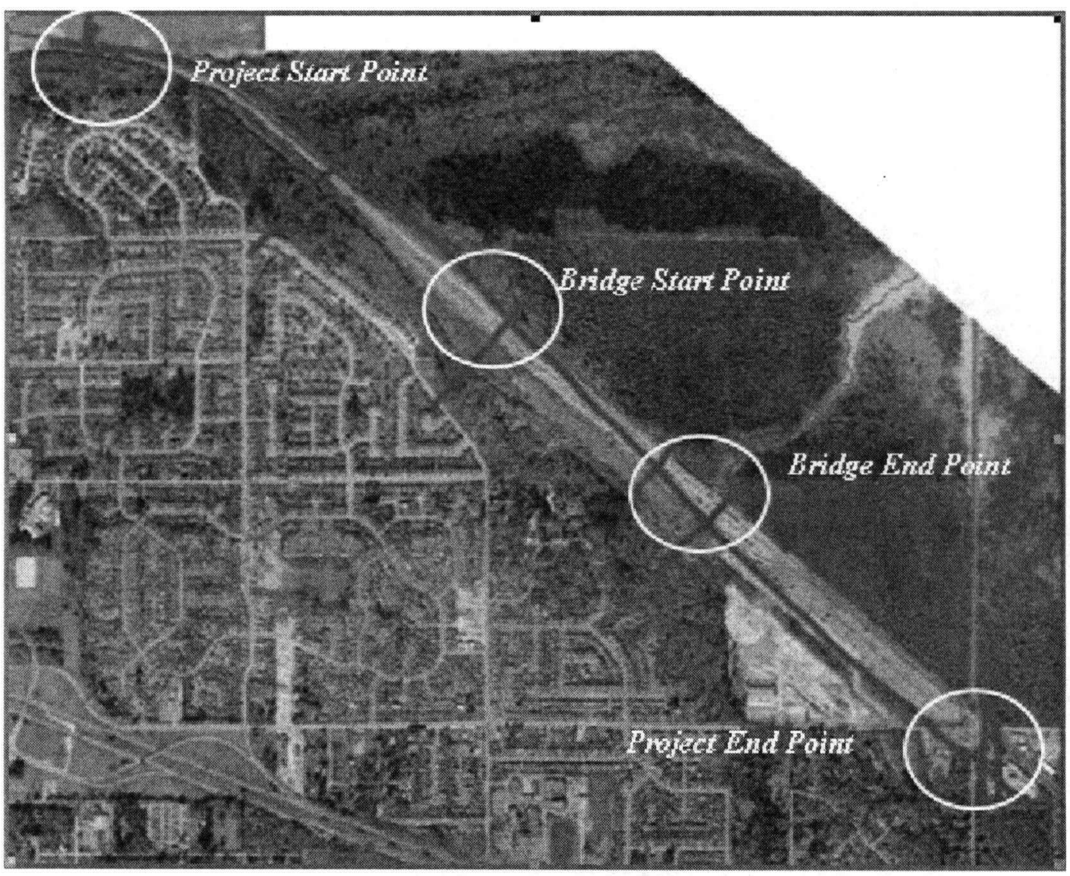


Figure 9: Area of the Project Defined by Client

The necessary coordinates were extracted from the 2D DWG files. The plan drawing is laid out such that the X and Y-coordinates correspond to the East and North respectively (Figure 10). The Z-coordinate was identified by determining the change from the plan drawing and measuring the Elevation from the profile drawing (Figure 11).

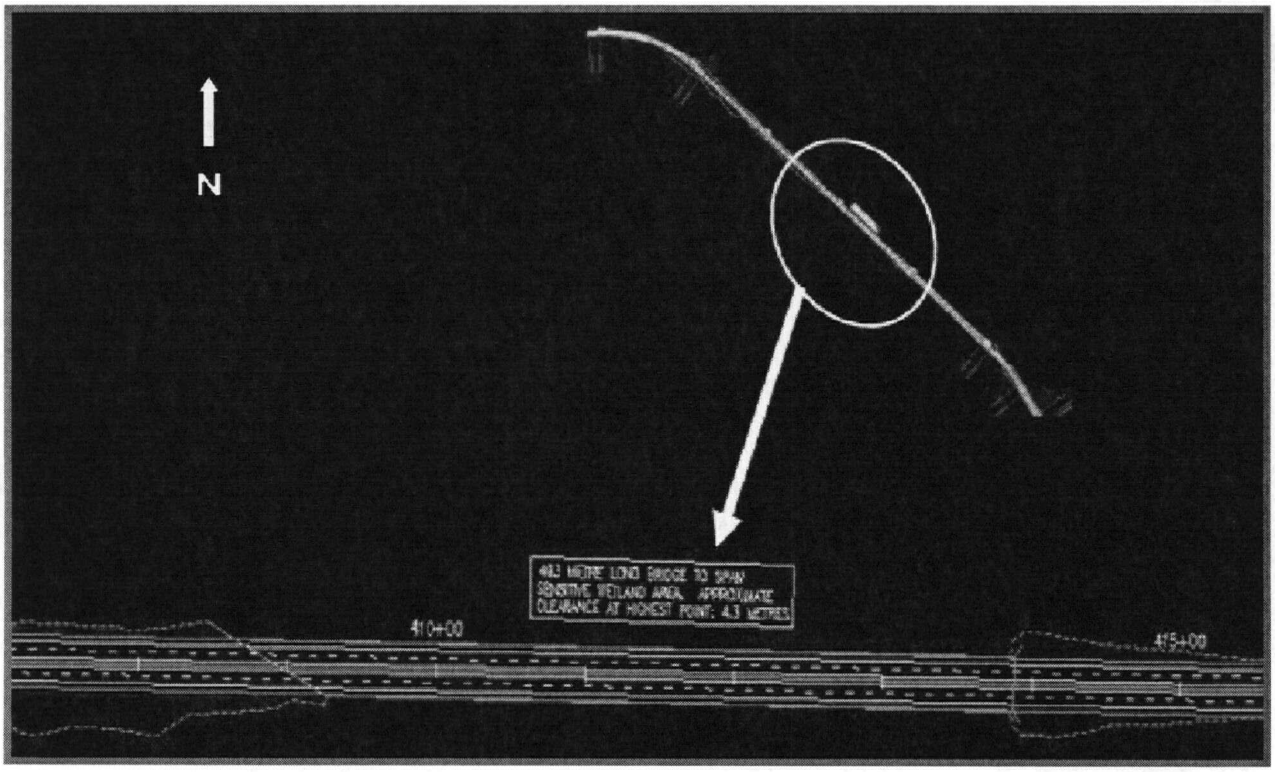


Figure 10: 2D Plan of the Bridge & Road

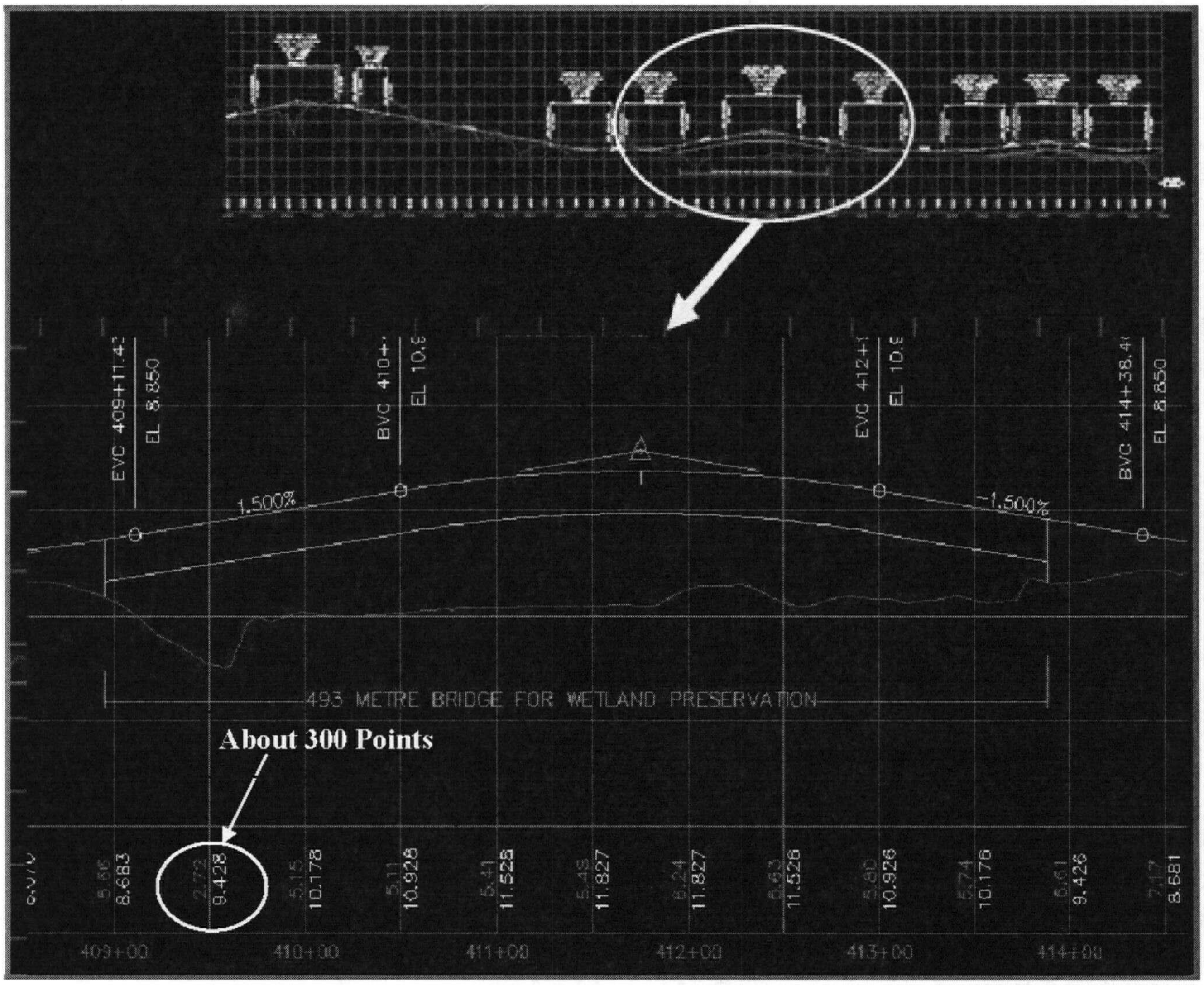


Figure 11: Profile of the Bridge & Road

There were three coordinates for each point (Distinguished in Figure 11) in the plan and profile, which had to be integrated in one DWG file as the base of building the 3D model. Due to the fact that there were about 300 points that came from the profile drawing, putting them one by one in ADT and using the "point" command was tedious and time consuming. Therefore, we developed a method to accelerate the process.

Data for each point were put in Microsoft Excel in a way that the X, Y and Z coordinates of each point were in the same row. Then, for each and every point, the "point" word was added in separate cell before the X coordinate cell in each row (Figure 12).

	A	B	C	D
1	*POINT*	*410*	*456*	*10.178*
2	*POINT*	*410.5*	*572*	*10.928*
3	*POINT*	*411*	*631*	*11.528*

Figure 12: Snapshot of the Excel File

Subsequently, this file exported to ADT. Connecting these points together gave us a 3D path of the bridge and road. This path was used as the base and guideline for building the 3D bridge and road.

The coordinates that have been used to model the 3D line were extracted from the center line of the road and bridge. Therefore, 3D models of the road and bridge had to be built in a way that this line passes through the center line of them. The center line of the bridge, regarding the 2D drawing, passes through the deck without considering the position of the piers.

The next step was to find the start and end point of the bridge or in other words, finding the position of the bridge in the 3D line. By using the marked image (Figure 4), the profile and the plan of the road, the coordinates of the start and end point of the bridge were approximately identified.

Then, by using the sectional drawings of the road and bridge, which was just a 2D drawing on the paper, and based on feedback from Delcan representative, Stephen Dubreuil, the road and deck of the bridge were modeled. The modeling process will be illustrated thoroughly in the next sections.

4.2.2 Modeling the Road

In our 3D model, the road has the concrete median and a concrete guard for each 500 meter side. These were modeled as 4 different objects for each part of the road. In other words, our 2D drawing which was drawn with respect to the provided file (Figure 13) included one object as sub grade, one object as a median and two objects as barriers. But on the other hand, the road consisted of two parts, one before the bridge and the other after the bridge. The road on the bridge was considered as part of the bridge.

The only available drawing as a guideline for modeling the section of the road was a typical drawing in the PDF format (Figure 13). The first step was drawing this typical section in ADT in order to have a DWG format of the section. Then, this drawing was scaled with respect to the scale of the 3D line that was described before. After that, the 2D section drawing was put at the beginning of the line in a way that the section was perpendicular to the line and also the line started from the center line of the section (Figure 13).

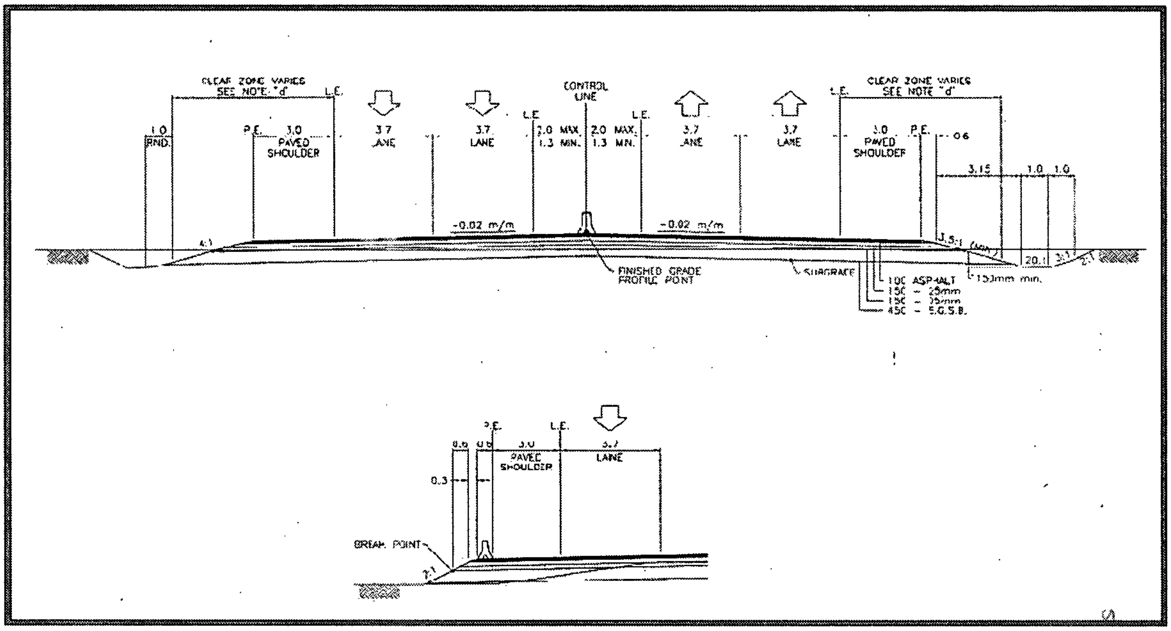


Figure 13: Typical Section of the Road

In order to make a 3D object out of the 2D drawing, the type of the line that the 2D drawing was made from, had to be changed in ADT. In other words, the typical line in the 2D drawing had to be changed to "Polyline Line" or "P Line". This type of line is used for 3D modeling in ADT, and has the special properties that can be used for modeling everything in 3D. In other words, if any 2D drawing in ADT is used in 3D modeling, the type of the line has to be "P Line". This made the 2D drawing into one object that can be extruded along another P Line with the aim of making a 3D model (Figure 14). The same procedure was followed for the second part of the road on the other side of the bridge.

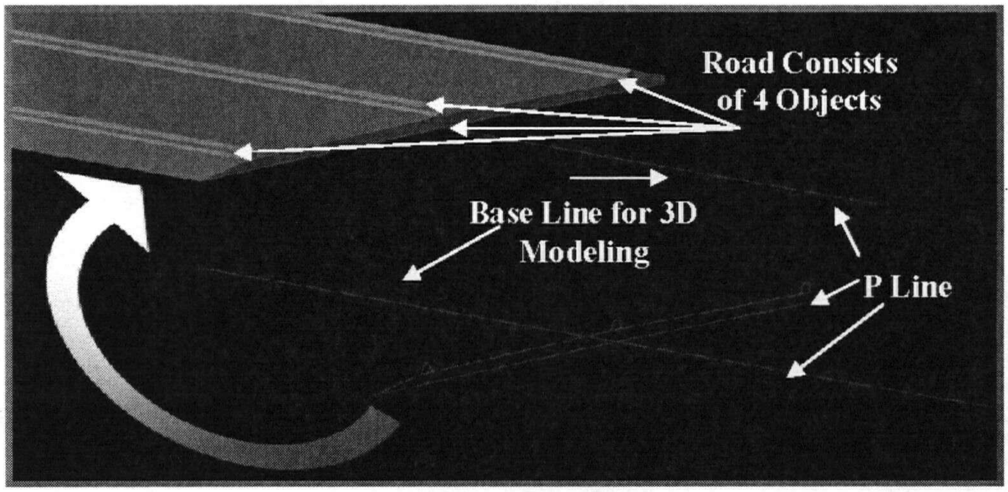


Figure 14: Extruding the Road Section

The only problem with this method was the fact that the whole road was considered as one 3D object by ADT, and this made it difficult to assign special properties and materials for the road and median, separately. On the other hand, since the focus of the project was on the bridge and also other methods were time consuming, this was acceptable.

4.2.3 Modeling the Bridge

Regarding the fact that there were just some design sketches of the piers, and a hard copy of the sectional drawing of the bridge deck, modeling the bridge in 3D format for the first time included many challenges.

The sectional drawing did not have enough dimensions and details for 3D modeling. Moreover, the sketches did not show the exact shape of the piers, and it did not have any dimensions. Therefore, the first model of the bridge had to be made with some assumptions and approximations.

Generally, modeling the bridge for the first time consisted of two main parts: the bridge deck and the piers. The deck consisted of two trapezoidal segments in every 2 meters (Figure 15). The method for modeling the deck was similar to the road. First, based on the available drawings, a section of the deck was modeled in 2D. After that, this drawing was scaled regarding the road and 3D line and was put at the start point of the bridge, perpendicular to the line. In this 2D drawing the whole bridge segments, median and barriers were modeled as one object. Then, this 2D drawing was extruded through the existing 3D line in order to make a 3D bridge.

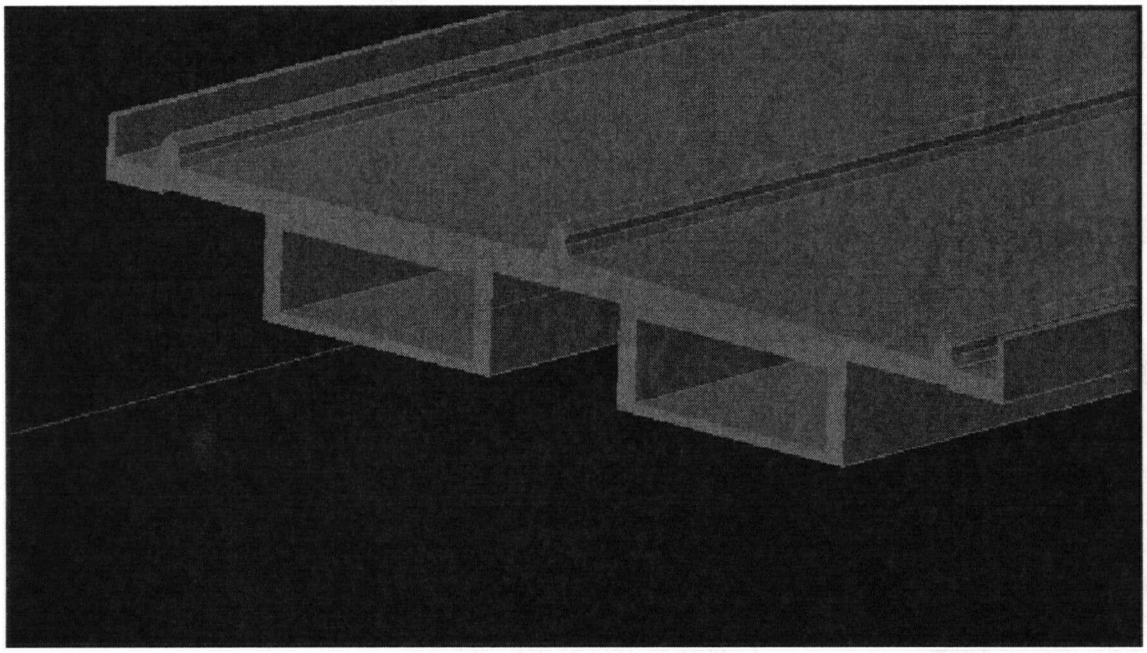


Figure 15: First Model of Bridge Deck

Since there was no DWG file for the piers, except for some sketches, this part of the bridge was modeled base on the sketches and some comments from the designer. The next step was to put piers in their positions along the bridge (Figure 16). For doing that, the profile of the road was used. There were some difficulties for putting each of these elements in their positions; for example with respect to the curve of the bridge and height of each pier, placing every pier needed an immense consideration as they were not equally spaced and there were no special arrangements for them. Further, up to this part there was no information about the height of the piers available.

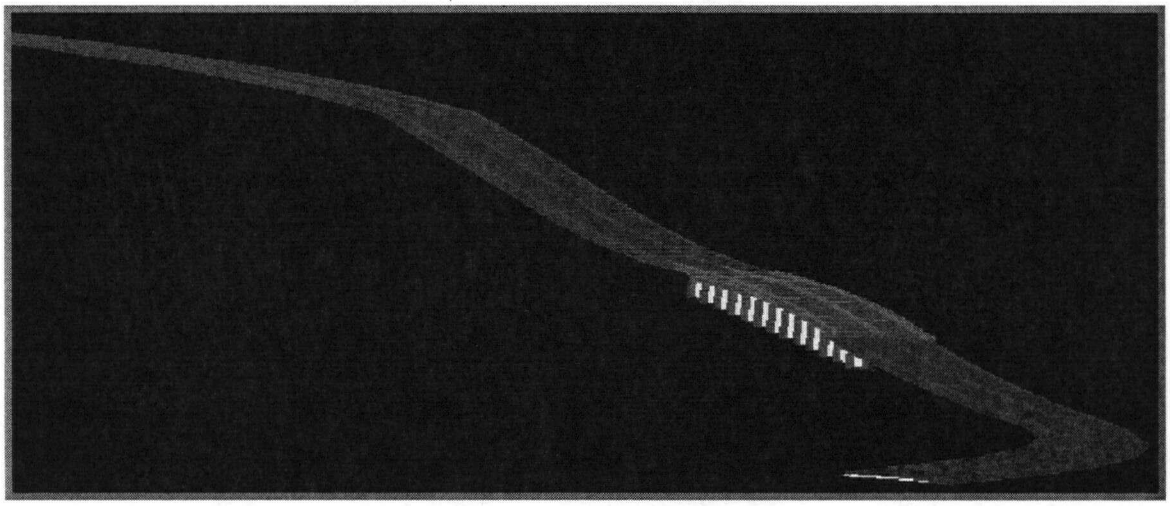


Figure 16: First Bridge & Road Model

After finishing the first model (Figure 16), a meeting was held to assess the progress with modeling and implementing the designer's comments. The design of the piers was changed by the designer. Also, they asked for changing the section of the bridge, and make the segments more real because the first model was not similar to the actual shape of the segments. In the provided model, the new design sketches and updated comments were implemented. The result was shown in the next meeting. The following pictures show 3D models of the piers (Figure 17) and the bridge (Figure 18).

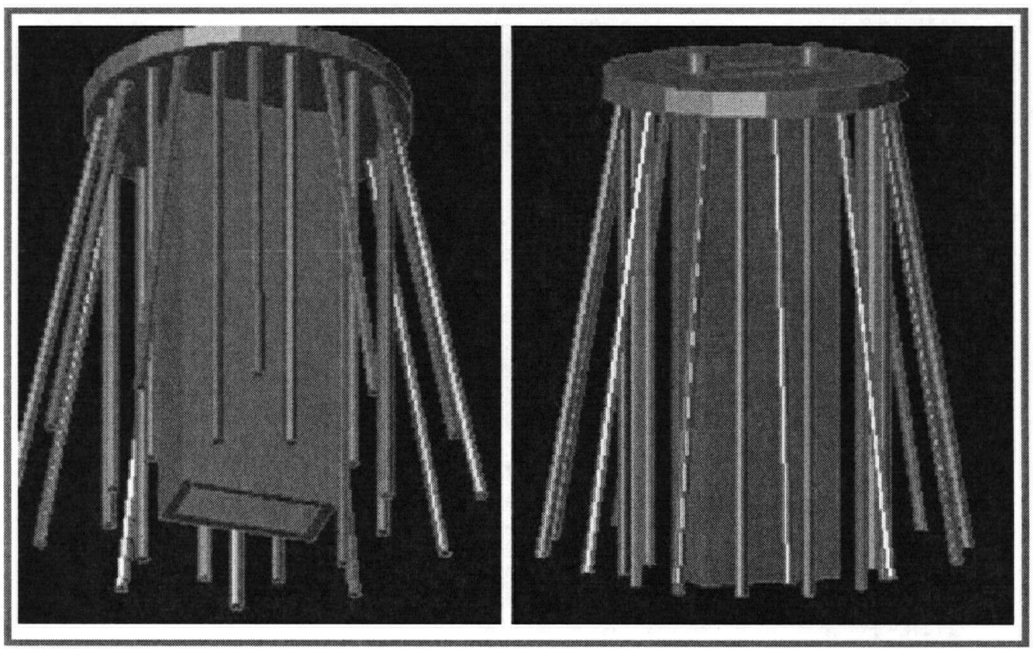


Figure 17: Second 3D Model of the Bridge Piers.

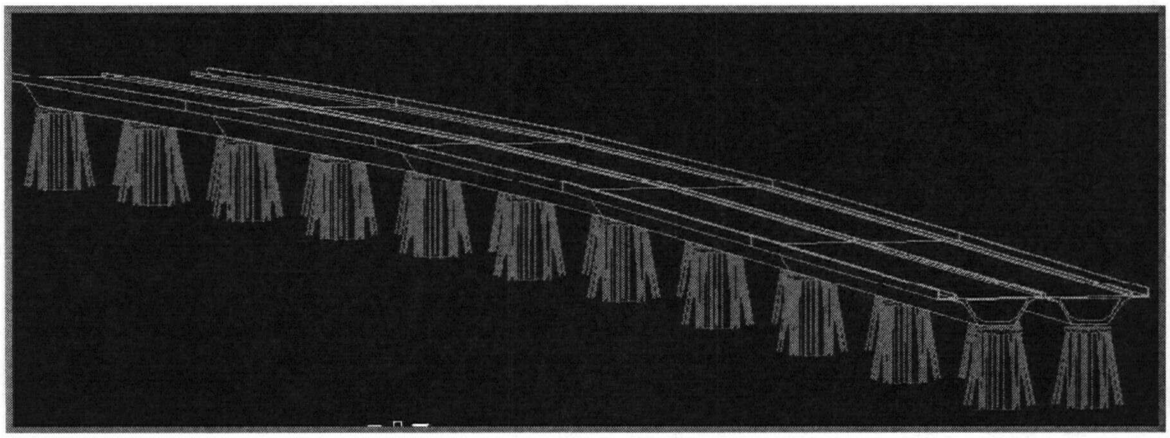


Figure 18: Second 3D Model of the Bridge.

In the next meeting, the designer had completely changed the design of the piers. Also, they added some temporary piers between each pier along the bridge due to their method of construction, and the sketch of the new piers and temporary piers were drawn in the meeting to facilitate 3D modeling. Further, in the previous design of the bridge deck the width of the bridge consisted of two segments, while in the new design four segments were considered (Figure 19). Therefore, the 3D model of the deck had to be changed as well.

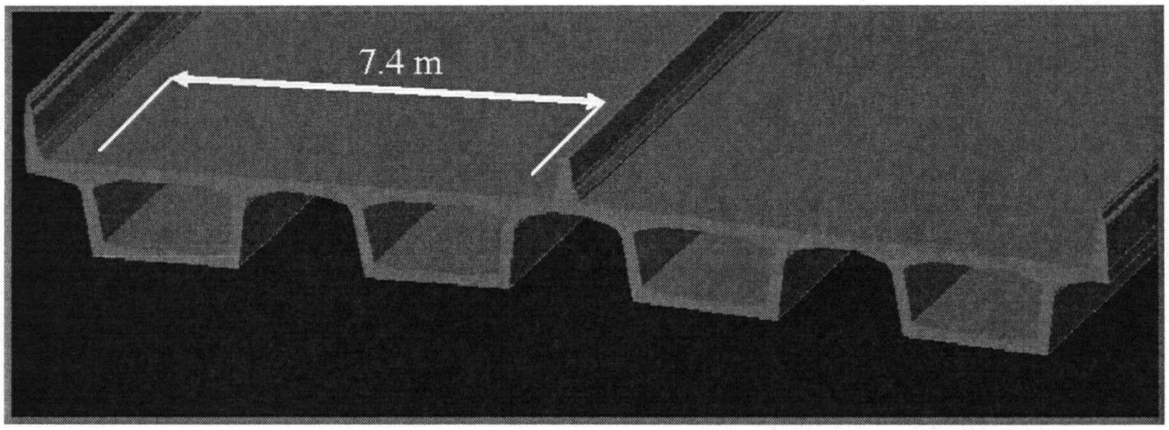


Figure 19: Third 3D Model of Bridge Deck

In order to make a new 3D model, the 2D DWG file was provided that contained sectional drawing of the bridge segments, and temporary piers with some dimensional details.

For modeling the piers and temporary piers, the construction method should have been approved, because it seems that each method has its own piers and some of them do not need any temporary piers. Therefore, the first task before modeling this part was to make sure of the method. This stage was passed by confirming the method which will be discussed in section 4.3.1.

Regarding the temporary piers, there was a sectional view of these parts along with different bridge sections. So, to comprehend the shape of them was rather hard. But, by taking comments from the designer team via email, the first model of temporary piers was built. And the third model was finished (Figure 20).

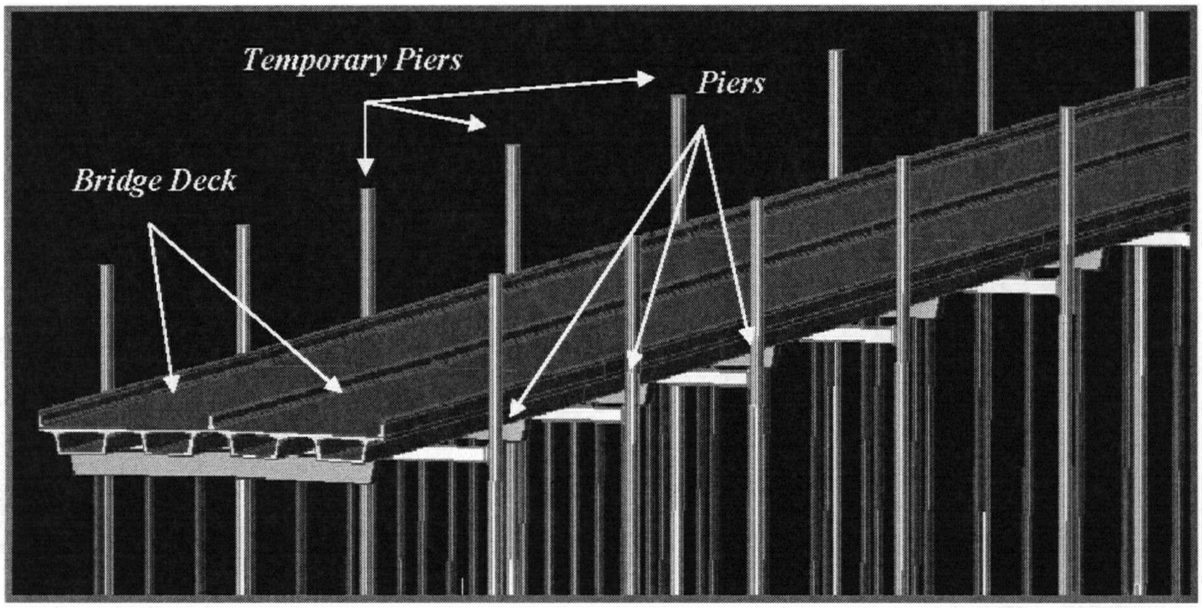


Figure 20: Third 3D Bridge Model.

I built the first 4D model based on the third version of the 3D bridge model. It should be mentioned that 3D and 4D modeling have reciprocal relations. In other words, after making the 4D model, it is often required to change the 3D model based on the construction schedule or method with respect to the changes that client might do the design or plan. Therefore, I will explain the rest of the bridge 3D modeling process during the 4D model procedure in section 4.3, in order to make the whole process more understandable. Essentially, from this point on, all changes to the 3D model were driven by schedule, method or design change. The next section will describe how I created 3D visualizations of the project landscape.

4.2.4 Landscape

During the process of 3D and 4D modeling, we had a specialist in landscape visualization help us make the model more realistic. We used Visual Nature Studio (VNS) software to create a landscape visualization. We created the 3D bridge model and landscape model simultaneously and the new version of the bridge in each major stage was added to the VNS model (Figure 21 & 22).

Figure 21: Landscape Visualization of the Project Produced By VNS

3D bridge objects were imported into the model. An aerial photograph was draped on the terrain. Houses in the subdivision were added to the model, and a series of still images were rendered. The most recent bridge model has been included, but new versions were in progress (Figure 22 & 23).

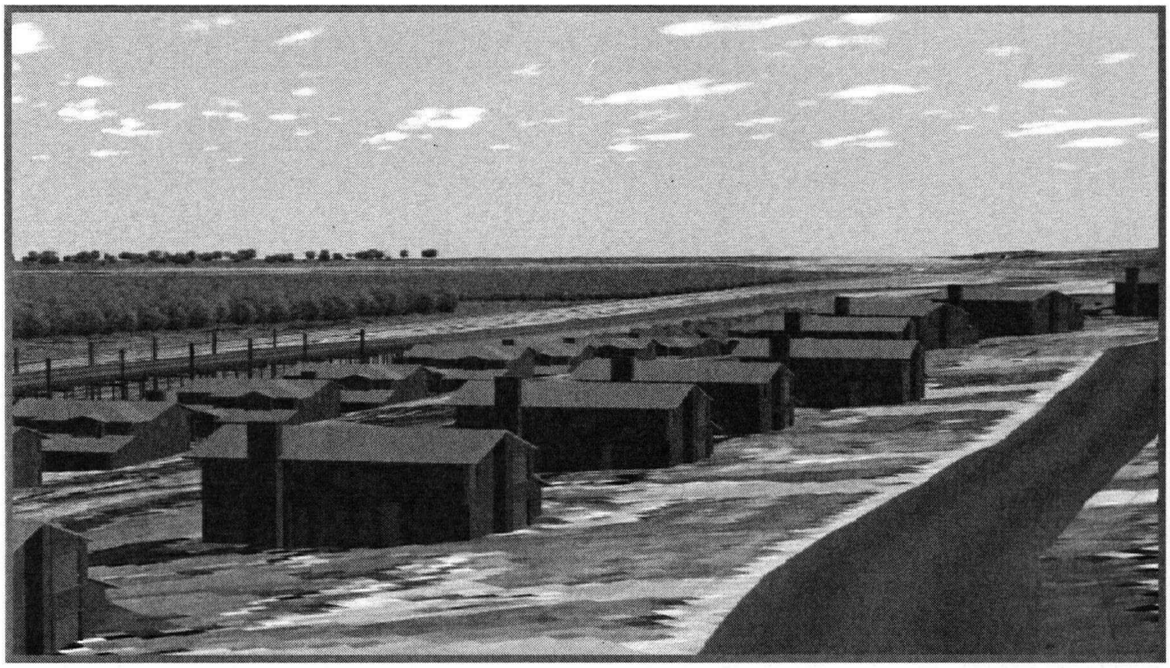


Figure 22: 3D Objects in the Landscape Produced by VNS

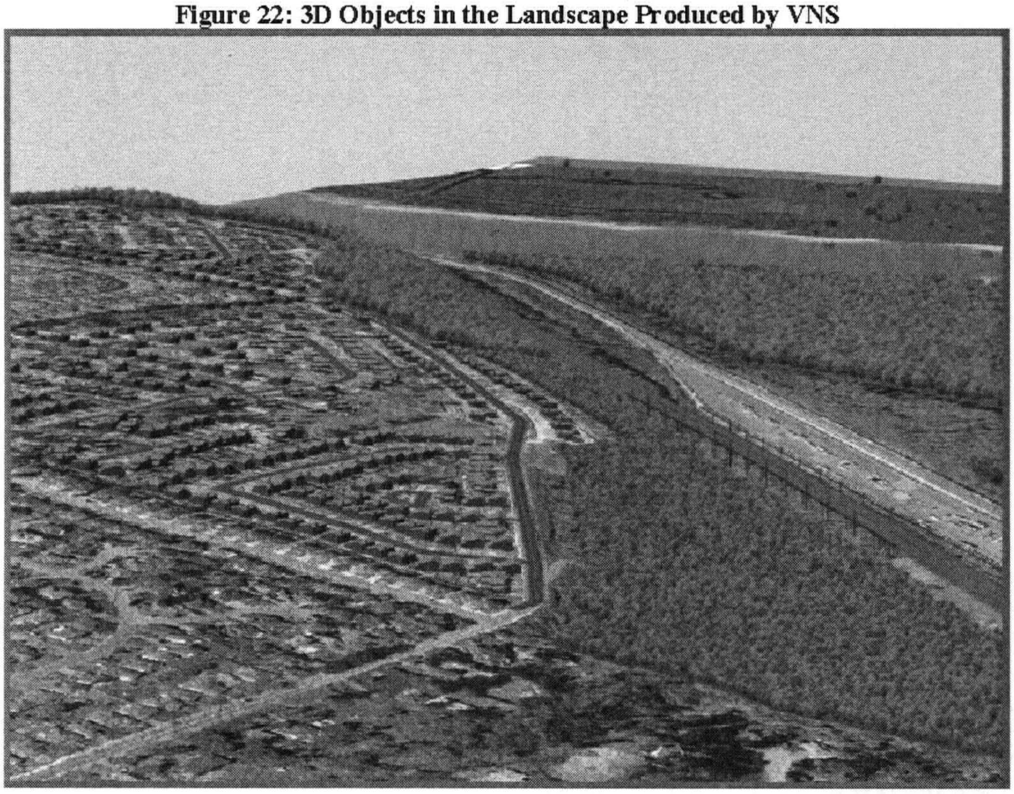


Figure 23: View of the Project Landscape and 3D objects by VNS

Finally, I created a fly through for our model by exporting the VNS file into NATUREVIEW, a free product developed by 3DNATURE group. This file enabled us to have a fly through over the area that has been modeled in VNS (Figure 24, 25 & 26).

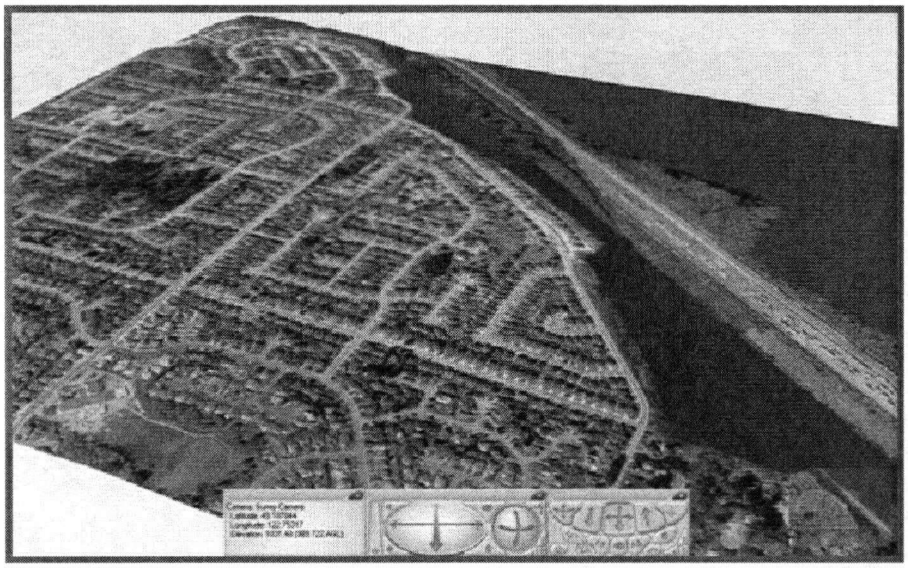


Figure 24: NatureView; an Export Product from VNS

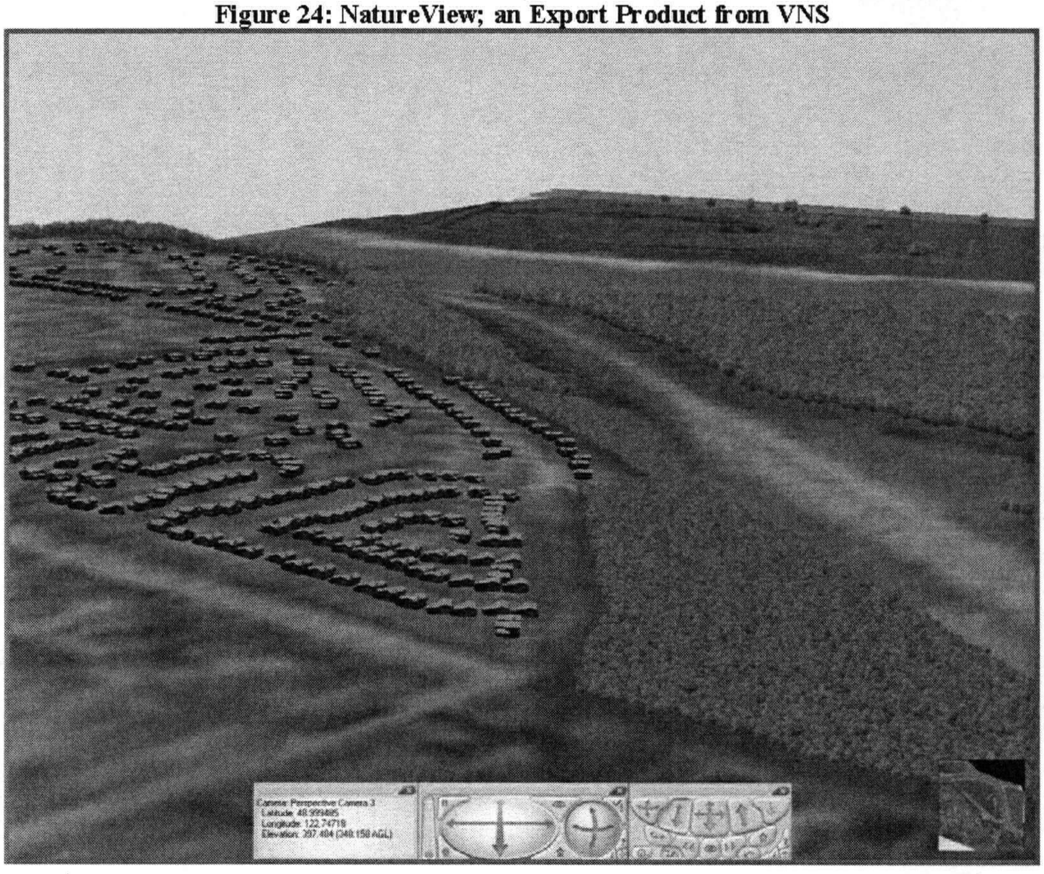


Figure 25: NatureView; an Export Product from VNS

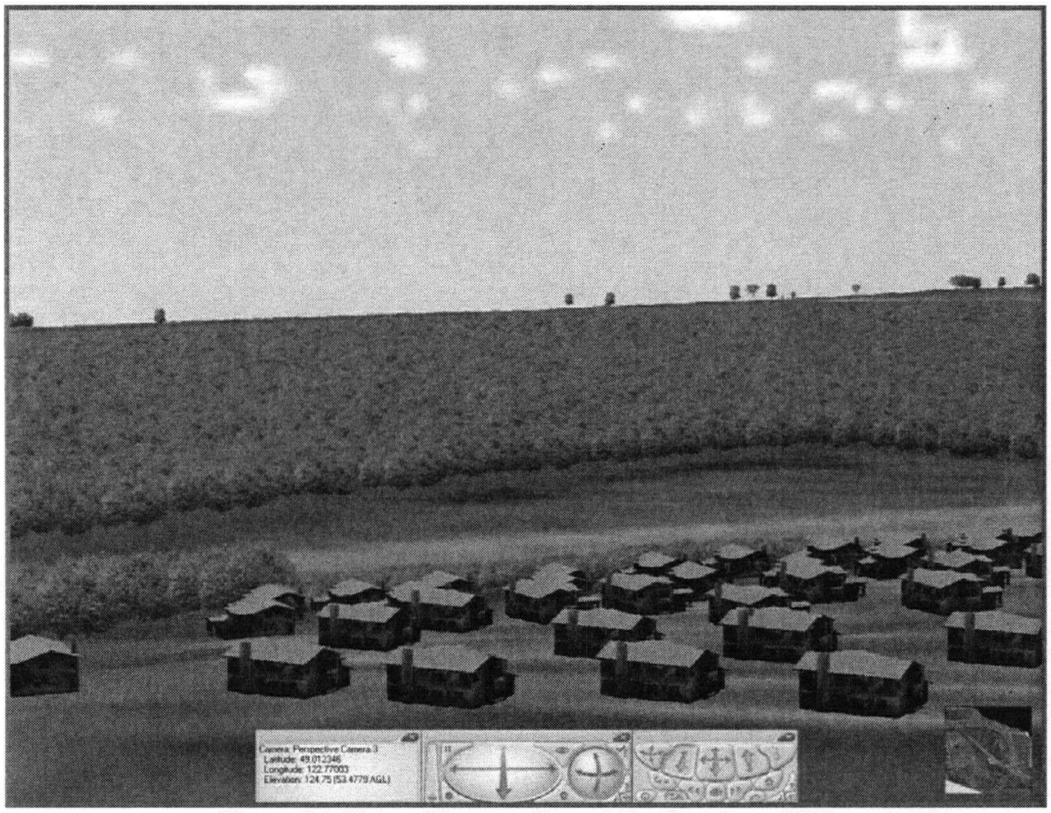


Figure 26: NatureView; an Export Product from VNS

The next step was importing the VNS model into ADT and NavisWorks. Theoretically, this was possible base on the User's Manual of this software under some conditions. The exporting process needed the add-on program which was "Scene Express". Since VNS only exports in special format, we had to choose the right file type. Regarding ADT and NavisWorks it was known that the only exporting format known by these software was 3D Studio Max format.

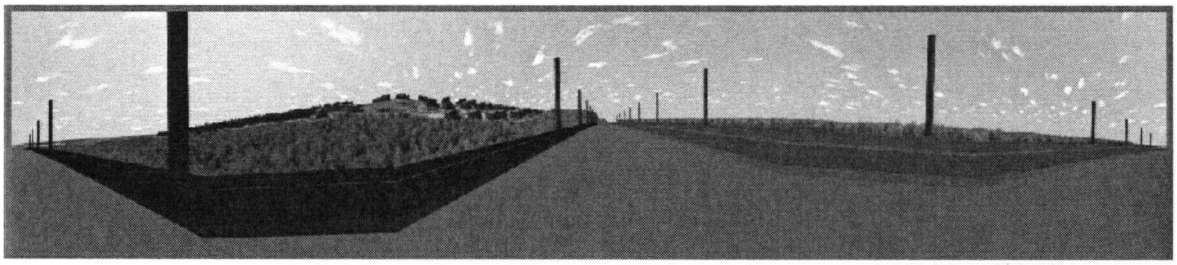


Figure 27: Panoramic View of the Bridge in the Landscape Produced by VNS

The plan was to export the file to 3DS and then import it into ADT. Then we would make the necessary adjustments in the model and save it as DWG file, and finally import the file into NavisWorks.

Unfortunately, after several tries the exporting procedure was not successful. VNS crashed at the last stage of finalizing the export. This procedure was repeated many times. At first we thought this was from conflicts between the different sets of software or necessity for more powerful computer. After changing the settings and condition several times we concluded that changing those conditions could not help. In other words, we tried every possible condition, but VNS still crashed at the finalizing stage.

Different procedures were tried, with different conditions. As it can be seen from the following figures (Figure 28 & 29) all the options in different tabs in the exporter dialogue box was changed in order to achieve the 3DS file. But for most of them VNS crashed at the last stage, and for the rest, the produced file did not work in 3DS or ADT. In other words the file was not considered as 3DS file and it seemed that the export file was produced with error.

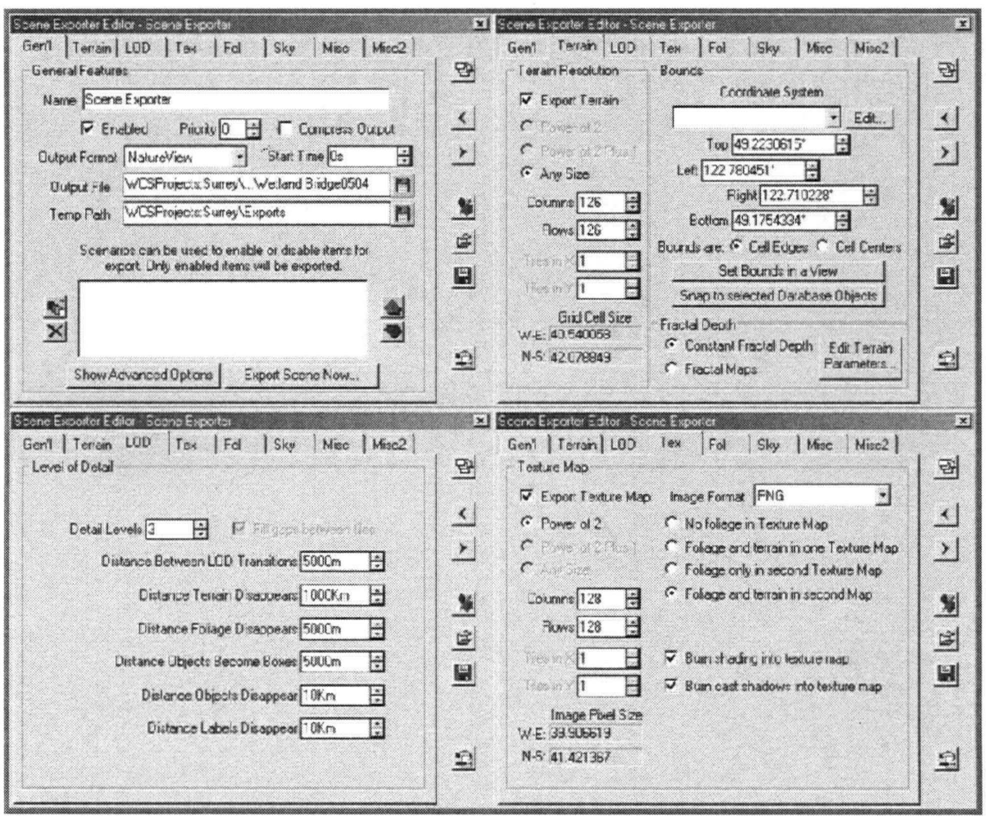


Figure 28: Scene Exporter Editor in VNS (1)

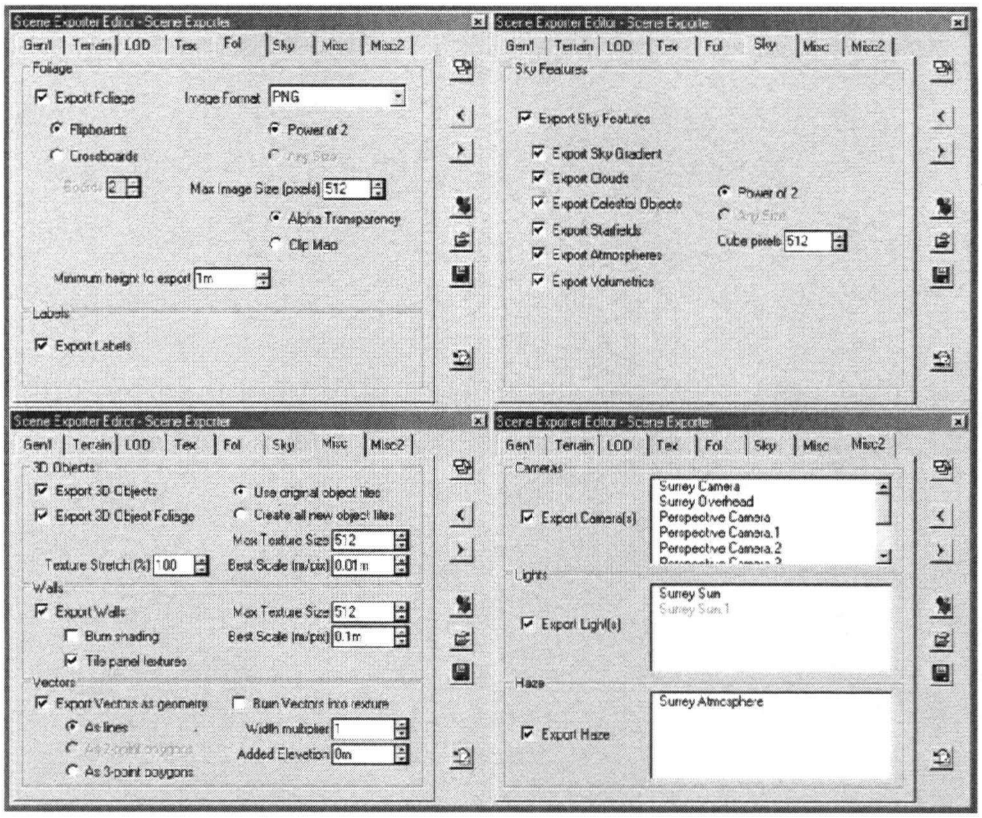


Figure 29: Scene Exporter Editor in VNS (2)

One of the procedures which we tried was to split the VNS model by playing with different settings in Scene Express (Figure 19 & 20) and export it separately. The only useful result of this process was a 3D mesh of the terrain without any objects such as trees or houses (Figure 30). The mesh was useful because we could put our bridge and road on it and attach images to it, which will be illustrated in the 4D section.

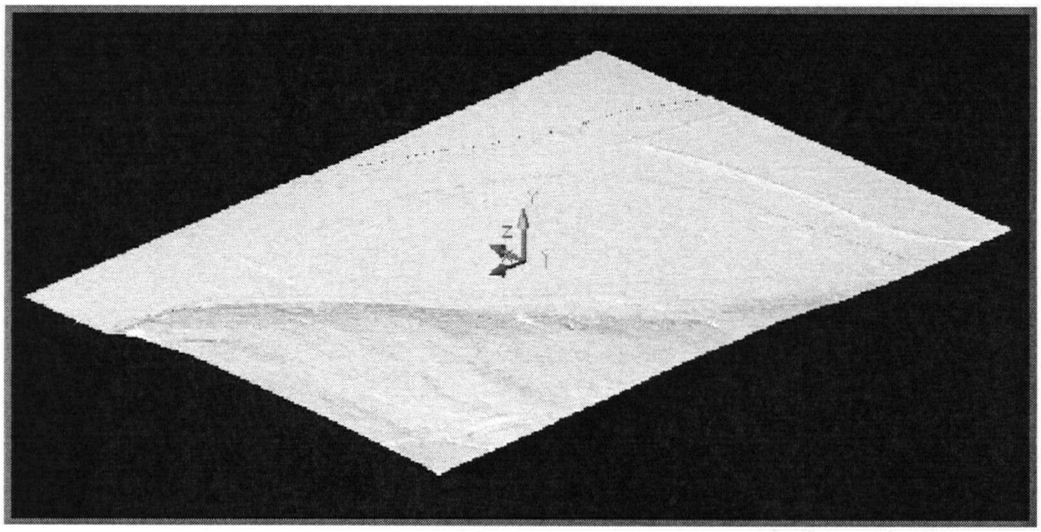


Figure 30: 3D Mesh Exported from VNS to ADT

4.2.5 Critique, benefits and limitations

During the utilization of different sets of software in the project, regarding the depth of the work, many issues have been encountered. In this section, the benefits and limitations of each sets of 3D software along with some critique will be provided. It should be noted that this overview is based on the experience with the software during the project and does not represent the actual capability of them. In other words, these software tools have more features which were not possible for us to explore and use regarding the time limitation.

4.2.5.1 Benefits

- Autodesk Architectural Desktop (ADT) is powerful software tool for all types of 3D modeling. The collections of properties in different fields give the user complete flexibility for modeling a variety of objects in 3D. Literally it is possible to make a three dimensional version of everything with this software.
- When it comes to the design of buildings and other facilities, this software can propose various pre-designed and ready to use 3D objects from its object library. The other benefit of this software for 3D modeling is its integration capability with other sets of software such as 3D Studio Max or NavisWorks, which makes it much easier to build a 3D model. In our project, we had to work simultaneously with ADT, 3D Studio Max and NavisWorks all the time, and this characteristic helped us to accelerate and enhance our work.
- Creating the 3D model of the bridge helped the designers to visualize their work, understand the problems and make changes where it is necessary.
- Using 3D and VNS model in this project helped the Ministry of Transportation to communicate more effectively with the stake holders and public to show the final situation in the area of the project, and help them to visualize the area of their community after the construction.

4.2.5.2 Limitations

- Although ADT has many properties for animation and rendering, it is better to use other software like 3D Studio Max for these purposes. We tried to make an animation of a crane for our project, but because of the features in ADT for this purpose it was hard, so we decided to use 3DSMax.
- We tried to make the 3D model as real as possible, but due to the fact that a bridge consists of many details and we have a time constraint, it was not possible to model every thing.
- The environment around the bridge and the road was not modeled realistically and thoroughly in ADT. The VNS model, represents the area more realistically due to its properties for modeling the environment.
- We could not export the VNS file into 3DS in order to enhance our 3D model this was a significant limitation because it diminished the realism of our 4D model.
- ADT does not have any special predefined road and bridge objects to help us in the process of 3D modeling.
- Using this software needs a powerful computer; otherwise it works so slowly or crashes when a huge file like our project file runs. This caused a lot of problem for us at the outset of the project, because we did not have a very powerful computer at that time, and even after we received a powerful computer it was sometimes still very slow.
- The major problem with this software, no matter how powerful your computer is, is the fact that as the file gets bigger, it is harder to work and interact with. Regarding this problem, adding objects like trees, houses and cars to the model could not have been done easily. We tried this during the project, but since the file was huge the software crashed often. Moreover, when a huge file is rendered, the quality of the rendering reduces when user utilize zooming or flying over the model. We experienced this many times with this project, specially during the meetings with the client and the designer
- It is hard to locate an exact position in the huge 3D file in this software, and even if it can be located, interacting with that can be challenging. For example when it is necessary to put a 3D object with the special scale over the exact location in the

huge file, it can be very difficult. We had this problem when we wanted to put the bridge over the terrain, and also when we decided to put a crane over the bridge which was much harder because the file was bigger than before.

The next section describes our process for creating the 4D model.

4.3 4D MODELING

"Traditional construction planning tools, such as bar charts and network diagrams, do not represent and communicate the spatial and temporal, or four-dimensional, aspects of construction schedules effectively. As a consequence, they do not allow project managers to create schedule alternatives rapidly to find the best way to build a particular design. Extending traditional planning tools, visual 4D models combine 3D CAD models with construction activities to display the progression of construction over time" (Fischer, CIFE website).

Dr.Fischer and his research team at Stanford University have organized 4D modeling tasks into three main groups of tasks: tasks to generate and manipulate 4D models, tasks to visualize and evaluate 4D models and tasks to deliver and distribute 4D models. In our project we tried to cover the first and second part of these tasks.

Three main tasks are involved in the generation of a 4D model and can be categorized as follows: (1) preparing a 3D model of the design, (2) generating a schedule and (3) connecting the objects and components in 3D model to tasks in the schedule.

4.3.1 The Construction Schedule

The first task of creating a 3D model was described in section 4.2. This section will describe the remaining tasks for creating a 4D model. So far in our project, we have the 3D model complete, but the schedule needs to be prepared. Defining the construction method was the key driver in creating the schedule. With respect to different methods, five vague sketches were provided at the first meeting. Later, two methods were cancelled by the designer due to environmental constraints. In the next meetings they offered the most important construction method. Generally, in this method the bridge will be built piece by piece as it moves forward. In other words, the construction for the bridge will take place on the previously built segments as it goes forward. As an illustration, the first pier and temporary pier will be built, and then the trapezoidal segments will be placed one by one by crane under support of the pier and temporary pier. After building the first span, the construction equipment will be placed on this span in order to make the second span. This process will continue until the last span. This was the first draft of the approved method which was changed slightly during the project. Figure 31 shows the first draft of the construction schedule. The first 4D model was made based on this schedule.

	Task Name	Duration	Predecessors
1	Mobilize	1 day	
2	Construct SE Abutment	19 days	1
3	Construct Pier 1	17 days	1
4	Construct Falsework	3 days	1
5	Install Span 01	12.5 days	2,3,4
6	Erect Temp Pier 1	2.25 days	5
7	Install 1st Half Span 2	5 days	6
8	Construct Pier 2	17 days	7
9	Install 2nd Half Span 2	10 days	8
10	Erect Temp Pier 2	2.25 days	9
11	Install 1st Half Span 3	5 days	10
12	Construct Pier 3	17 days	11
13	Install 2nd Half Span 3	10 days	12
14	Erect Temp Pier 3	2.25 hrs	13
15	Install 1st Half Span 4	5 days	14
16	Construct Pier 4	17 days	15
17	Install 2nd Half Span 4	10 days	16
18	Erect Temp Pier 4	2.25 days	17
19	Install 1st Half Span 5	5 days	18
20	Construct Pier 5	17 days	19
21	Install 2nd Half Span 5	10 days	20
22	Erect Temp Pier 5	2.25 days	21
23	Install 1st Half Span 6	5 days	22
24	Construct Pier 6	17 days	23
25	Install 2nd Half Span 6	10 days	24

Figure 31: First Draft of Project Schedule Provided by Delcan

After showing the 4D model based on this schedule during a meeting, the MoT representative requested a more detailed 4D model, so Delcan agreed to provide us with the more specific schedule shown in Figure 32. The second version of the schedule was very detailed, and since we were asked by MoT to model portion of the construction details, such as showing the construction of the false work piece by piece, many details were not necessary for our 4D model. Therefore, I changed the schedule to support 4D modeling (Figure 33). In this version, I added tasks or divided some tasks that were necessary for the 4D model such as adding 6 separate tasks for the construction of abutment piles. I also deleted those tasks that were not essential such as tasks for installing all segments in every span of the bridge (Figure 33).

	Task Name	Duration	Predecessors
1	Mobilize	1 day	
2	**Construct SE Abutment**	**152 hrs**	**1**
3	Excavate	1 day	1
4	Piling	6 days	3
5	Rebar	3 days	4
6	Formwork	1 day	5
7	Pour Concrete	1 day	6
8	Cure Concrete	7 days	7
9	**Construct Pier 1**	**136 hrs**	**1**
10	Excavate	1 day	1
11	Piling	6 days	3
12	Rebar	2 days	11
13	Formwork	0.5 days	12
14	Pour Concrete	0.5 days	13
15	Cure Concrete	7 days	14
16	**Construct Falsework**	**168 hrs**	**1**
17	Clearing & Grubbing	1 day	1
18	Earthworks	1 day	17
19	Piling	16 days	18
20	Install Temp Beams	16 hrs	8,15,19
21	**Install Span 01**	**100 hrs**	**8,20**
108	**Erect Temp Pier 1**	**18 hrs**	**107**
111	**Install 1st Half Span 2**	**40 hrs**	**107**
162	**Construct Pier 2**	**136 hrs**	**161**
169	**Install 2nd Half Span 2**	**30 hrs**	**168**

	Task Name	Duration	Predecessors
1	Mobilize	1 day	
2	**Construct SE Abutment**	**152 hrs**	**1**
9	**Construct Pier 1**	**136 hrs**	**1**
16	**Construct Falsework**	**168 hrs**	**1**
21	**Install Span 01**	**100 hrs**	**8,20**
22	**Segment 01-01**	**3 hrs**	**20**
23	Place Segment 01-01	2 hrs	20
24	Epoxy Segment 01-01	0.5 hrs	23
25	Temp Tendon 01-01	0.5 hrs	24
26	**Segment 01-02**	**3 hrs**	**25**
30	**Segment 01-03**	**3 hrs**	**29**
34	**Segment 01-04**	**3 hrs**	**33**
38	**Segment 01-05**	**3 hrs**	**37**
42	**Segment 01-06**	**3 hrs**	**41**
46	**Segment 01-07**	**3 hrs**	**45**
50	**Segment 01-08**	**3 hrs**	**49**
54	**Segment 01-09**	**3 hrs**	**53**
58	**Segment 01-10**	**3 hrs**	**57**
62	**Segment 01-11**	**3 hrs**	**61**
66	**Segment 01-12**	**3 hrs**	**65**
70	**Segment 01-13**	**3 hrs**	**69**
74	**Segment 01-14**	**3 hrs**	**73**
78	**Segment 01-15**	**3 hrs**	**77**
82	**Segment 01-16**	**3 hrs**	**81**
86	**Segment 01-17**	**3 hrs**	**85**

Figure 32: Detailed Project Schedule Provided by Delcan

	Task Name	Duration	Predecessors
1	Mobilize	1 day	
2	⊟ **Construct SE Abutment**	**19 days**	**1**
3	Excavate	1 day	1
4	⊟ **Piling**	**6 days**	**3**
5	Pile1	1 day	3
6	Pile2	1 day	5
7	Pile3	1 day	6
8	Pile4	1 day	7
9	Pile5	1 day	8
10	Pile6	1 day	9
11	⊟ **Beam**	**12 days**	**4**
12	Rebar	3 days	4
13	Formwork	1 day	12
14	Pour Concrete	1 day	13
15	Cure Concrete	7 days	14
16	⊟ **Construct Pier 1**	**21 days**	**1**
17	Excavate	1 day	
18	⊞ **Piling**	**8 days**	**17**
25	⊞ **Beam**	**10 days**	**18**
30	⊟ **Construct Falsework**	**23 days**	**1**
31	Clearing & Grubbing	1 day	1
32	Earthworks	1 day	31
33	⊞ **Piling**	**16 days**	**32**
50	⊞ **Install Temp Beams**	**2 days**	**15,29**
59	Install Span 01	12.5 days	50

	Task Name	Duration	Predecessors
1	Mobilize	1 day	
2	⊞ **Construct SE Abutment**	**19 days**	**1**
16	⊞ **Construct Pier 1**	**21 days**	**1**
30	⊞ **Construct Falsework**	**23 days**	**1**
59	Install Span 01	12.5 days	50
60	⊟ **Erect Temp Pier 1**	**2.25 days**	**59**
61	⊟ **Piling**	**2 days**	**59**
62	Pile1	1 day	59
63	Pile2	1 day	62
64	Install Temporary Beam	2 hrs	63
65	Install 1st Half Span 2	5 days	60
66	Construct Pier 2	17 days	65
67	Install 2nd Half Span 2	10 days	66
68	⊞ **Erect Temp Pier 2**	**2.25 days**	**67**
73	Install 1st Half Span 3	5 days	68
74	Construct Pier 3	17 days	73
75	Install 2nd Half Span 3	10 days	74
76	⊞ **Erect Temp Pier 3**	**2.25 days**	**75**
81	Install 1st Half Span 4	5 days	76
82	Construct Pier 4	17 days	81
83	Install 2nd Half Span 4	10 days	82
84	⊟ **Remove Falsework**	**4.08 days**	**83**
85	Remove Temp Beams	3 days	83
86	Cut Piles	40 mins	85
87	Earthworks	8 hrs	86

Figure 33: Revised Project Schedule for 4D Modeling

4.3.2 4D Modeling Overview

Each 4D model consists of two main parts: the 3D Model and the Schedule. Any changes in each of these two parts resulted in changing the 4D model. Generally speaking, 3D and 4D modeling has a reciprocal relationship. In this project, we had to return to the 3D model many times to change it, and consequently this caused changes in the 4D model. However, making changes to the 4D model does not always relate to the 3D model. Sometimes during the project the schedule had to be changed in order to show the realism of the process in a way that satisfies the client. In this section, the general process of 4D modeling which was used in this project will be described.

The 4D model was prepared by exporting the 3D model from ADT and importing schedule from Microsoft Project into NavisWorks Jet Stream. Then we connected components in the 3D model with components in the schedule. This process was repeated many times during the project in order to make the most suitable and realistic 4D model

The first step was to export the 3D model from ADT into NavisWorks Jet Stream. In ADT there is a command for doing this which is "NWDOUT". When this command is typed in ADT, a dialogue box appears (Figure 34) and NavisWorks should be selected.

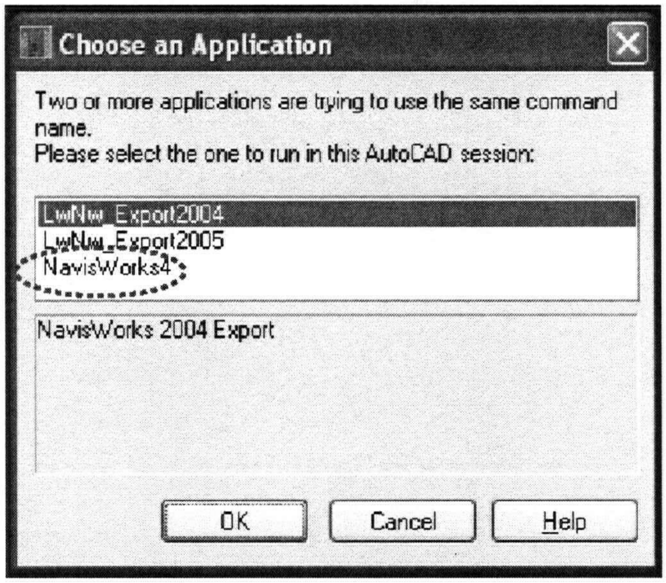


Figure 34: Choose an Application in NavisWorks

Then, another dialogue box will be presented to locate the destination for the file and choosing the name (Figure 35), and after that the whole ADT file will be exported.

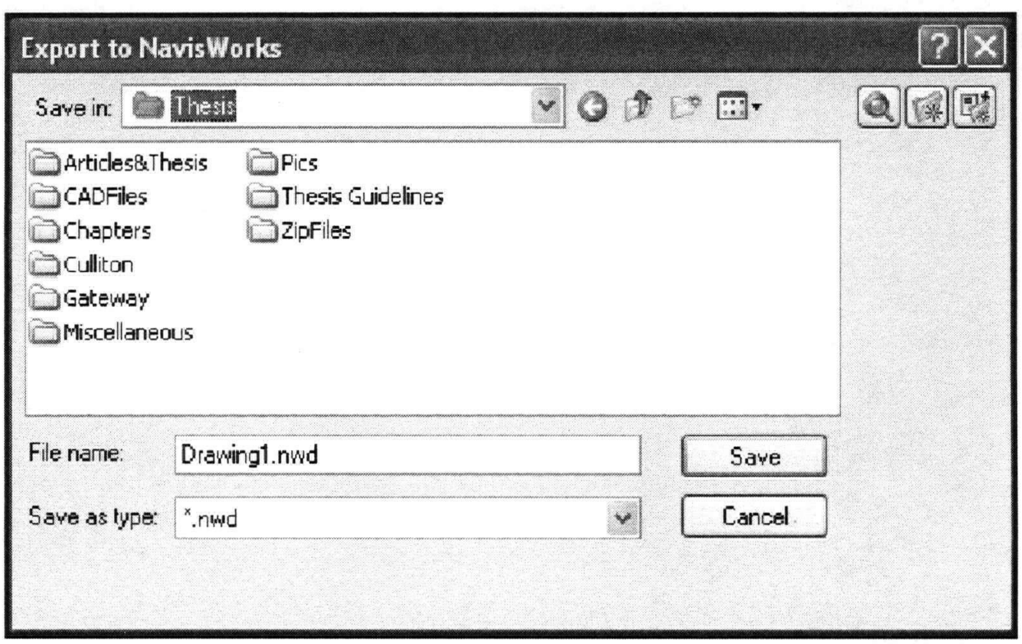


Figure 35: Export to NavisWorks Dialogue Box

Then in NavisWorks, just by using the File Menu and locating the exported file, it can be used in NavisWorks. After opening the file, the layers in ADT file will appear in Selection Tree in NavisWorks Jet Stream (Figure 36). It should be mentioned that each layer is treated as a separate object in NavisWorks. Even if you have multiple objects on a layer (e.g. sections of a bridge deck), it treats these objects as a single entity.

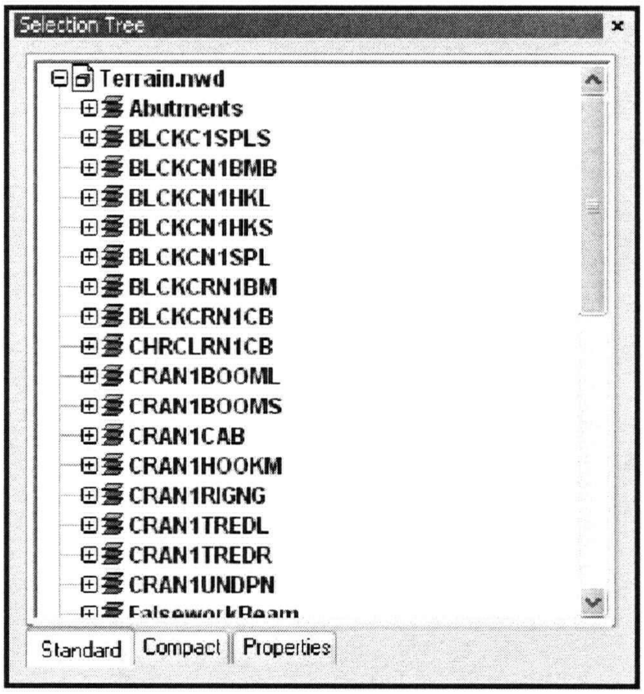
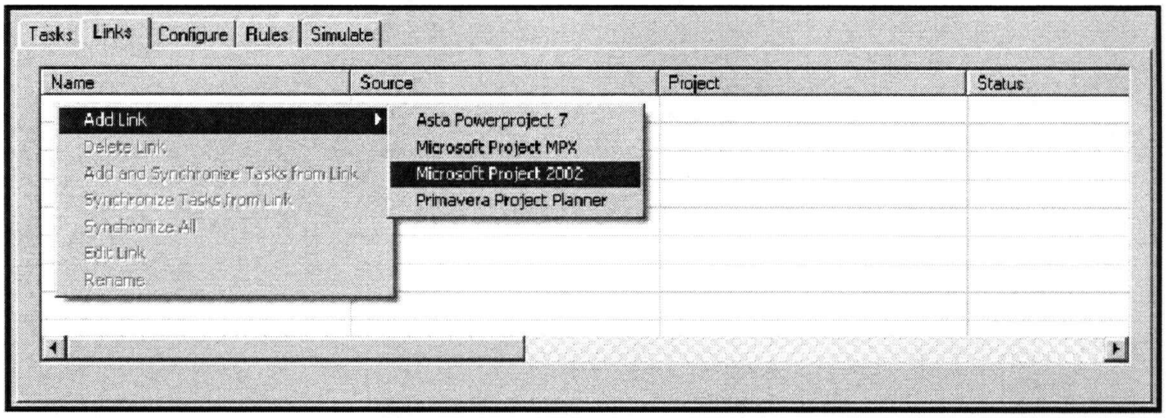


Figure 36: Selection Tree in NavisWorks after Export

The next step is import the schedule. In order to do that, the first step is to link the file to the schedule. In the menu bar choose Tools Menu, and in this menu choose Timeliner and the Timeliner toolbar will appear (Figure 37).

In the Timeliner the Links tab shows all of the links to external schedules in your project, listed in a multi-column format. The columns show link name, source (e.g. Microsoft Project), project, and link status. Any further columns (there may be none) identify the fields from the external schedule which specify the task type, unique id, start date and end date for each linked task (Figure 37). In this section the user can choose the schedule file.



Figur e37: Timeliner Toolbar

Then, the user right clicks on the link and chooses the "Synchronize Tasks from Link" option (Figure 38). All of the tasks in the schedule will then show up in the "Tasks" tab (Figure 34).

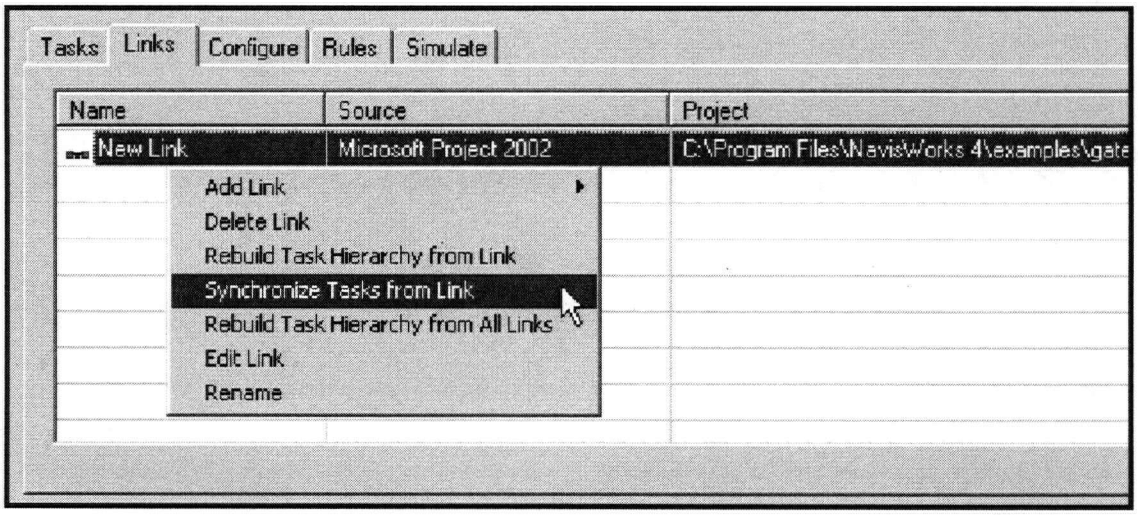


Figure 38: Synchronizing the Link

The Tasks tab shows all of the tasks in the schedule, listed in a multi-column format. The columns show task name; start date; end date; planned start date; planned end date; task type; whether any objects from the model are attached to the task; whether the task is linked to an external schedule; index of task in external schedule; and unique ID of task in external schedule (Figure 39).

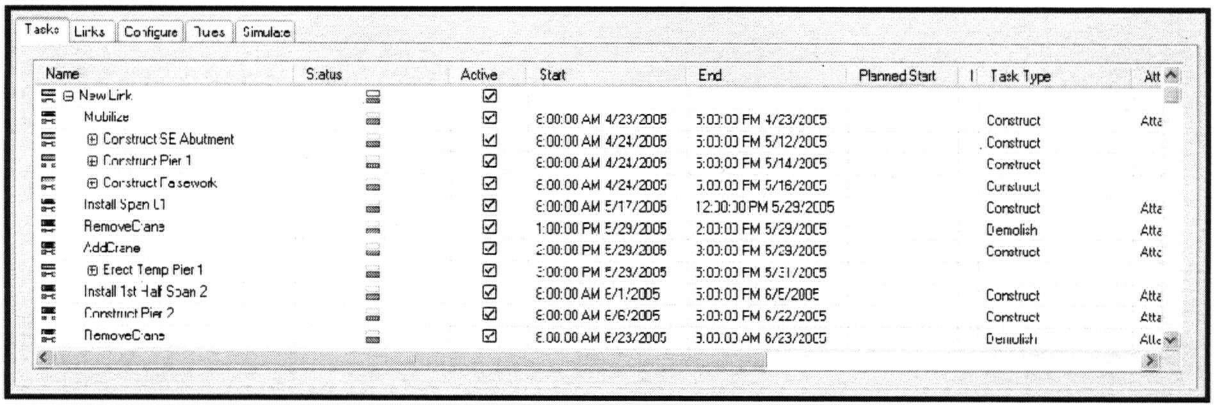


Figure 39: Tasks Tab in NavisWorks Timeliner

An icon is displayed to the left of each task. These identify the current status of the task, with relation to attached items and links to external schedules (Figure 40).

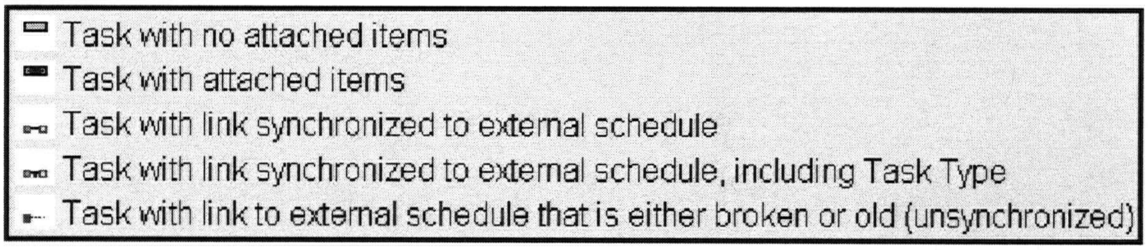


Figure 40: Tasks Icons

In order to attach a task to an object, first the user should select the object, and then right click on the task in the Tasks tab. A context menu will appear (Figure 41).

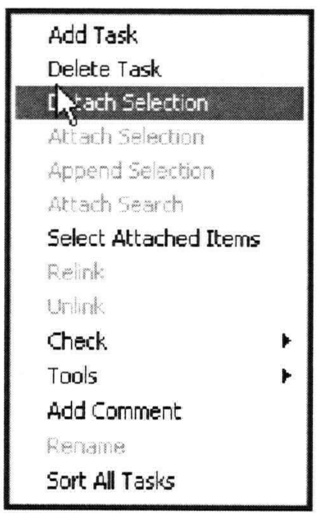


Figure 41: Context Menu

A context menu (Figure 41), allows the user to perform a number of functions to create, edit and check the tasks in the schedule. Also, by choosing "Attach Selection" a task will attach to an object.

In the next section, I will describe the 4D modeling process and also discuss the impacts of the 4D model on the requirements of the 3D model.

4.3.3 4D Modeling Process on Gateway

In general, the 4D model can be viewed from two perspectives: Macro-Level 4D model, and Micro-Level 4D model. By Macro-Level I mean showing the construction process from a large scale point of view and representing the general construction process. For example show the sequence in building the piers, temporary piers or deck spans. On the other hand, in a Micro-Level simulation, I tried to show the detailed construction process. As an illustration, I tried to show the method of putting the segments in each span together, or the sequence in building each part of piers and temporary piers.

The process of 4D modeling and related changes in 3D models will be illustrated in this section. Most of the work was done on Macro-Level part, while Micro-Level 4D modeling had the main role in understanding the construction process.

4.3.3.1 Macro-Level 4D Modeling Process

We built the first 4D model in NavisWorks based on the schedule shown in figure 26. We followed the steps in section 4.3.2 in our project in order to make the first 4D model. However, after viewing the 4D model in NavisWorks, the whole bridge spans appeared together, which did not convey the construction process due to the fact that the bridge will be constructed segment by segment. Therefore, the 3D model had to be revised, because when a model is exported from ADT to NavisWorks, all objects in one layer are considered as one object. So, it was necessary to separate the segments and consequently, the number of layers was equal to the number of segments In order to make separated segments, the 3D path line discussed in section 4.2.1, which was considered as the base for 3D modeling, had to be divided into the same length as each segment or set of segments (Figure 42). This process depended on the proposed schedule.

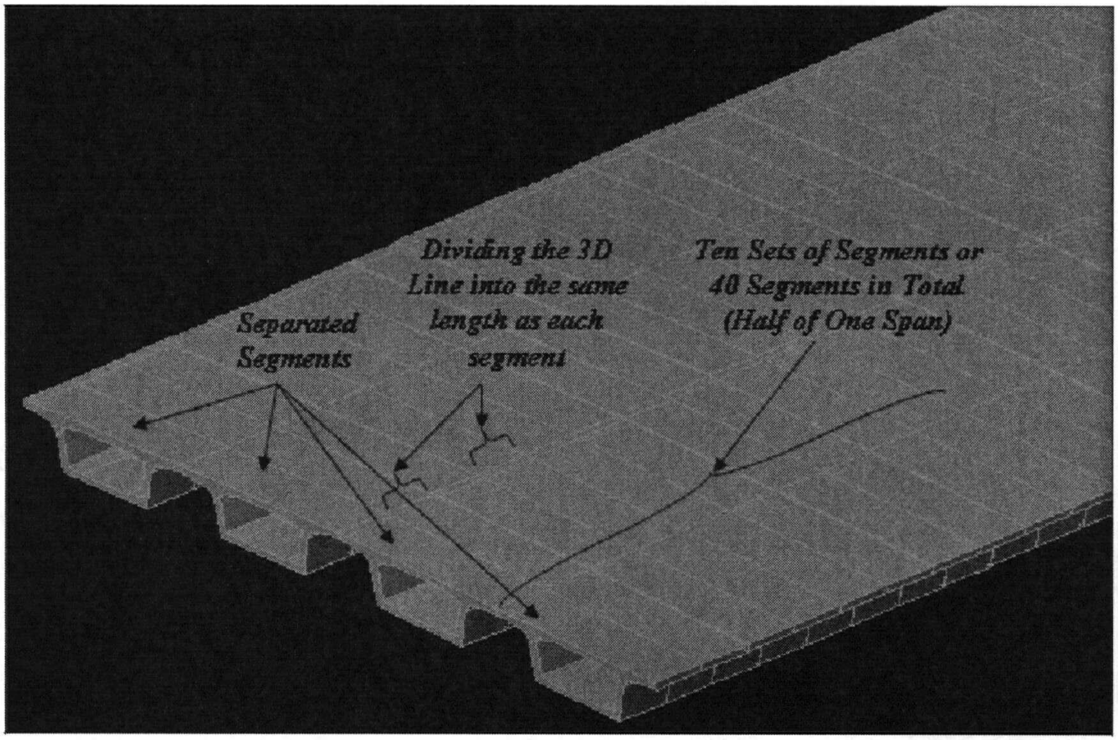


Figure 42: Bridge Deck Segments

Regarding the provided schedule, the duration was given for each span of the bridge which contains about ten sets of segments and forty segments in total (Figure 26). The method was to put the 2D sectional drawing at the start point of each span line that was divided, and then extrude the 2D sectional drawing along that line. This resulted in separate sets of segments in each span of the bridge. Therefore, it was possible to show the construction process for each set of segments in every span of the bridge.

There was a similar situation for piers and temporary piers; there was one duration time in the proposed schedule for each set of piers and temporary piers. As a result, after completion of the 4D model, the bridge seems to be constructed suddenly part by part, after some delay for each part (Figure 43).

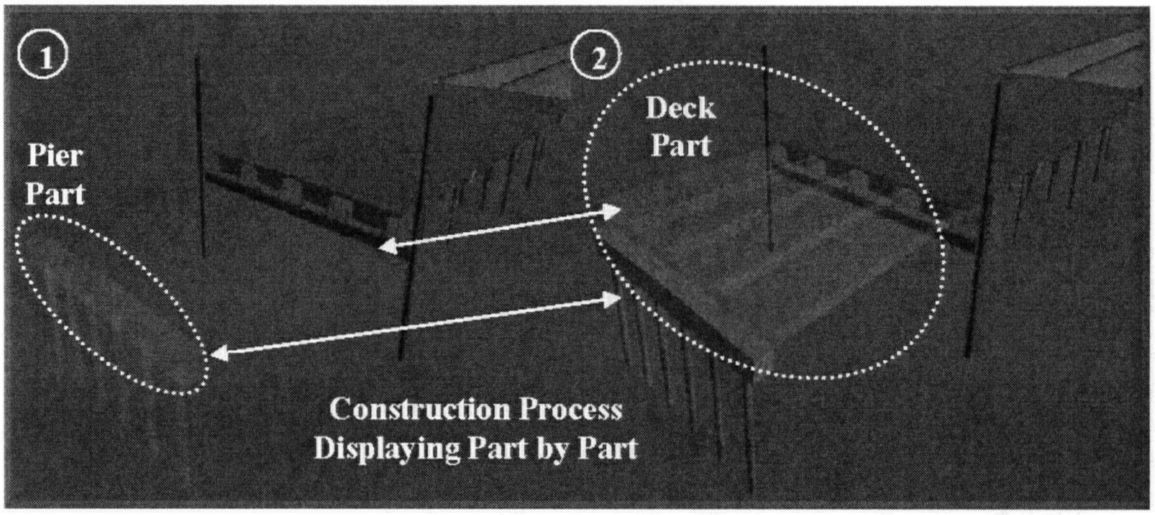


Figure 43: Macro 4D Modeling

During the 4D modeling, we were informed by Delcan that the number of temporary piers in the drawings was one more than the number of them in the schedule. It was considered as an unintentional error and the schedule was corrected. But during the next meeting with the client and designer representative, Delcan told us that the schedule was right and the drawing was wrong. This meant not only the 3D model, but also the 4D model had to be changed.

It was identified by the designer (Delcan) that the updated design had false-work at the first span instead of temporary piers. Also, the first and the last piers were replaced with the abutments which were very similar to the piers. Moreover, it was requested by MoT to make a 4D model that shows the bridge will be built segment by segment in order to convey what is really going to happen. Therefore, the Micro-Level 4D model had to be built which will be discussed in the next section.

We revised the 3D & 4D models based on the changes requested which included new abutments, more temporary piers and piers, and a break down of deck segments (Figure 44). Making the 3D model of the deck segment by segment was extremely time-consuming because of the scale and shape of each segment, and the number of segments that needed to be built for this purpose, which were about 600 single segments. Also connecting them together was challenging because of the curvature of the bridge and the number of segments involved.

Furthermore, considering the fact about layering the model which was mentioned above (Section 4.3.2 - Page 72), 4D modeling at this level of detail became difficult and tedious. As an illustration, about 600 layers had to be made in ADT just to show the 4D construction segment by segment. Further, changing the schedule for this purpose was much more confusing. Finally, connecting the task from schedule to objects in 3D model seemed to be unthinkable because it meant connecting about 1500 objects to about 1500 tasks and consideration our time constraints, we did not tried that.

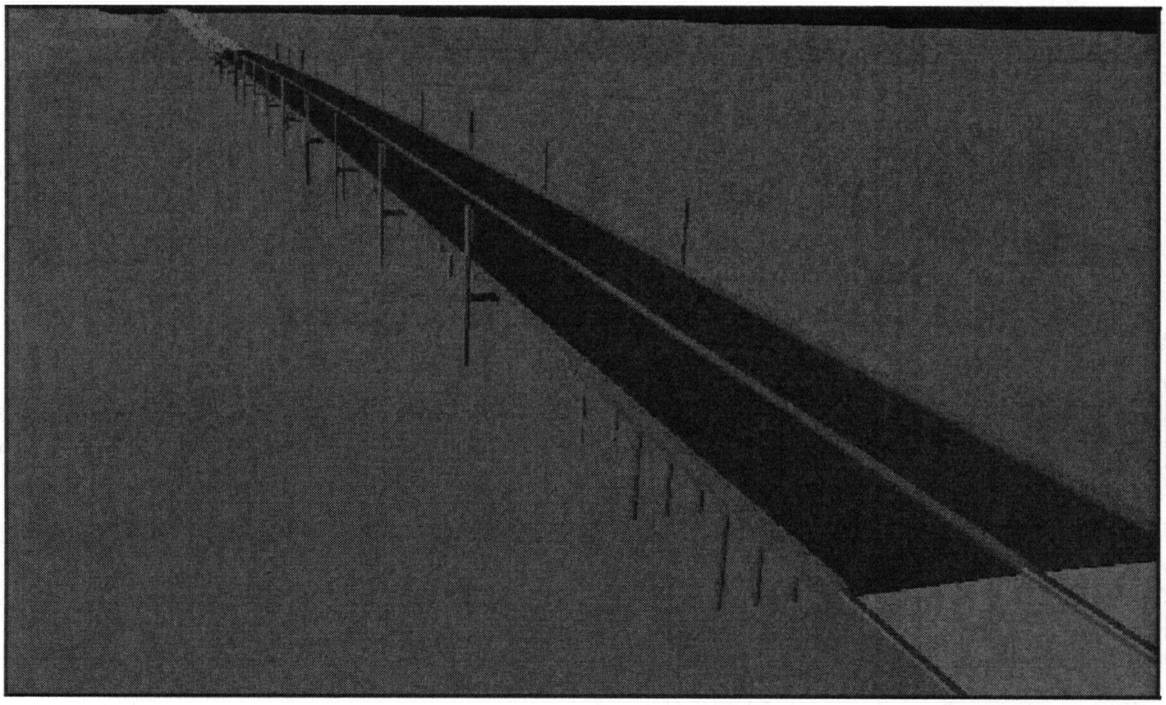


Figure 44: Final 4D Model

The problem was mentioned to Delcan and MoT. The response from Delcan was disappointing: "This IS a tedious process. This is why we don't do it." But, MoT agreed to make a segment by segment 4D model for just half of the last span, and for the false work, piers and temporary piers of the first two spans with the aim of showing the construction process in more details. This was considered as a Micro-Level 4D model.

4.3.3.2 Micro-Level 4D Modeling Process

I made the new 3D model for the purpose of Micro-Level 4D which included divided segments in different layers in the last span (Figure 45). After a while, an updated schedule was received, but the schedule did not have the necessary details about building the piers and temporary piers. Another schedule was requested for this kind of 4D modeling. Finally, they agreed that the schedule can be manipulated in order to make it useful for the Micro-Level 4D model.

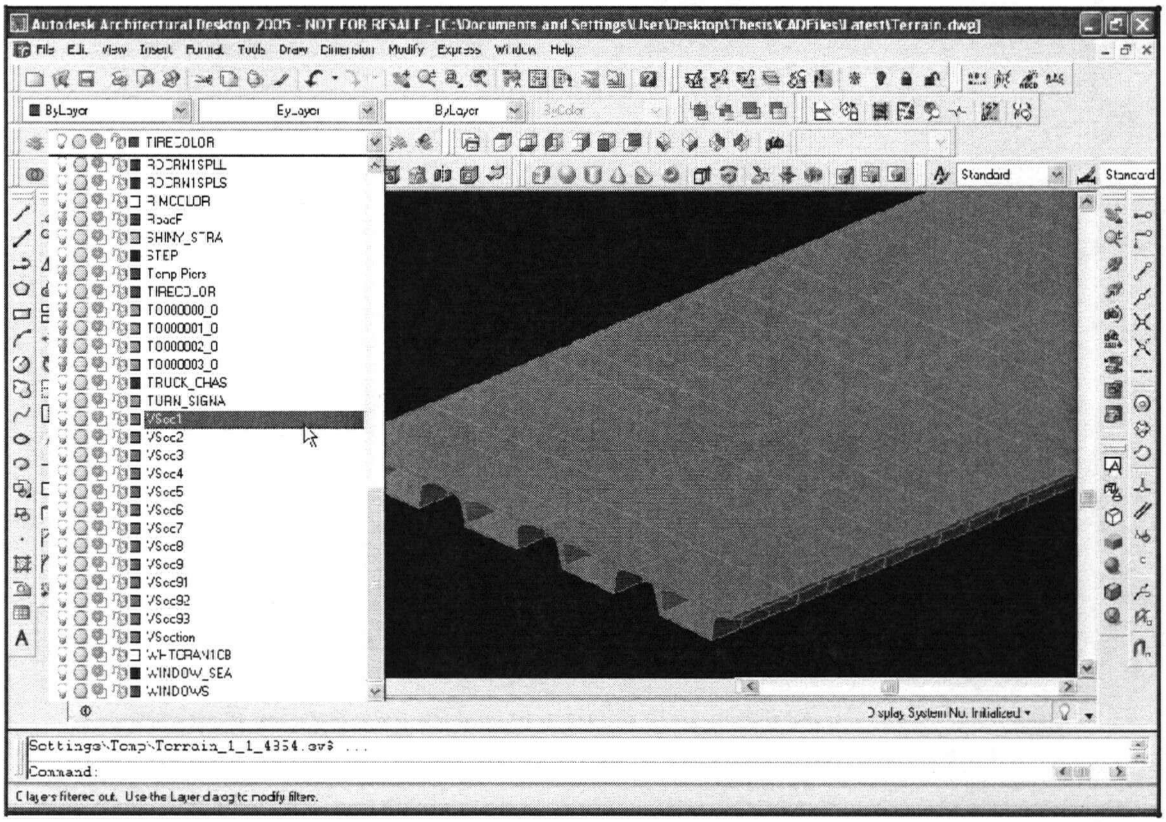


Figure 45: 3D Model for Micro-Level 4D Model

I changed the schedule due to the needs of 4D modeling, and broke a variety of tasks into subtasks. For example the "Erect Temp Pier1" task was divided into a "Piling" subtask and an "Install Temporary Beams" subtask. Also, the "Piling" subtask was divided into "Pile1" subtask and "Pile2" subtask (Figure 46). Then, for each of these subtasks the duration was assigned based on general knowledge of the construction method. But the sum of durations needed to be the same as the original durations for each task to be consistent with the Macro-Level 4D perspective.

	Task Name	Duration	Predecessors
1	Mobilize	1 day	
2	⊞ **Construct SE Abutment**	**19 days**	
16	⊞ **Construct Pier 1**	**21 days**	**1**
30	⊞ **Construct Falsework**	**23 days**	**1**
59	Install Span 01	12.5 days	50
60	RemoveCrane	1 hr	59
61	AddCrane	1 hr	60
62	⊟ **Erect Temp Pier 1**	**2.25 days**	**61**
63	⊟ **Piling**	**2 days**	**59**
64	Pile1	1 day	59
65	Pile2	1 day	64
66	Install Temporary Beam	2 hrs	65
67	Install 1st Half Span 2	5 days	62
68	Construct Pier 2	17 days	67
69	Install 2nd Half Span 2	10 days	68
70	⊞ **Erect Temp Pier 2**	**2.25 days**	**69**
75	Install 1st Half Span 3	5 days	70
76	Construct Pier 3	17 days	75
77	Install 2nd Half Span 3	10 days	76
78	⊞ **Erect Temp Pier 3**	**2.25 days**	**77**
83	Install 1st Half Span 4	5 days	78
84	Construct Pier 4	17 days	83
85	Install 2nd Half Span 4	10 days	84
86	⊞ **Remove Falsework**	**4.08 days**	**85**
90	Erect Temp Pier 4	18 hrs	86

Figure 46: Revised Project Schedule for Micro-Level 4D Modeling

As can be seen in Figure 47, the false work in the first span (snapshots 1 and 2) and the segments in the last span (snap shots 3 and 4) are displayed segment by segment.

The 4D model was prepared and the result was shown to the client and designer during the meeting. Unfortunately, Delcan had given us an inaccurate schedule. The 4D model illustrated the fact that the temporary piers should remain after erection while in process, and then dismantled, and erected again as the bridge goes forward (Figure 48). It was mentioned by the designer, that there will be only 4 sets of temporary piers and they will be dismantled one by one after making each span of the bridge (Figure 49).

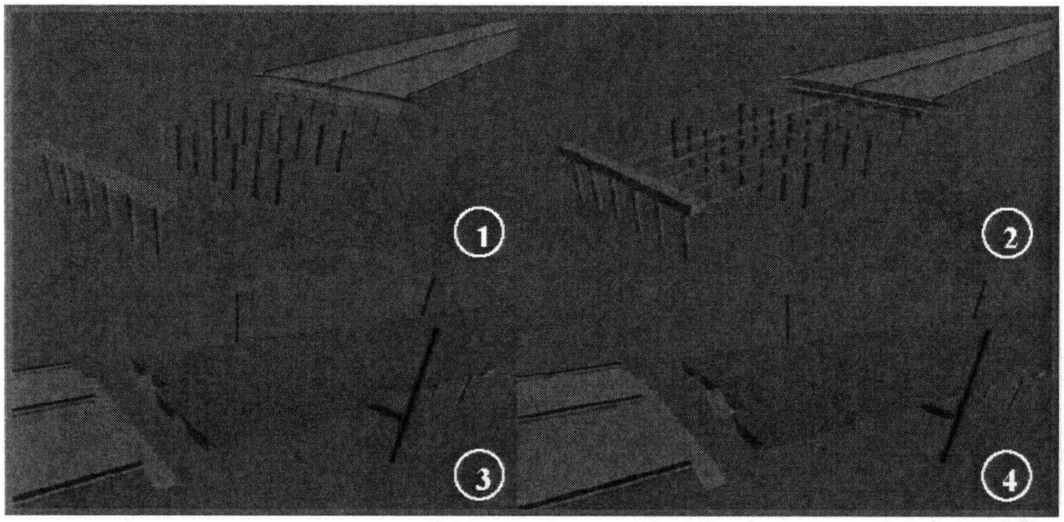


Figure 47: Micro 4D Modeling

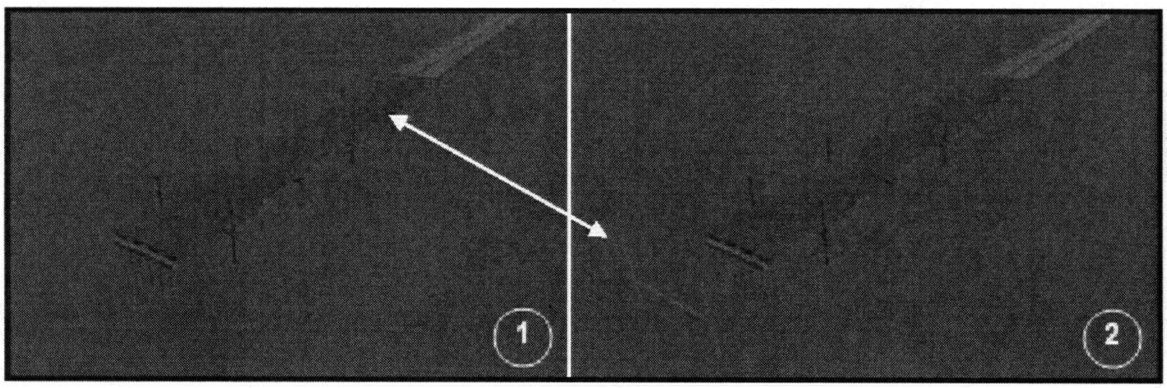


Figure 48: Dismantling the Temporary Piers

On the other hand, the MoT representative asked us to separate the construction of medians and guards of the bridge from the main deck, add guard-rails above the concrete guards, and add a side-walk beside the road way. He was told by the designer that based on the drawings there will not be any side-walk, guard rails, or lightening on the bridge due to environmental concerns.

To divide the median and guard rails, we had to make new layers in the 3D model as discussed previously. However, because we made a segment by segment 4D model for the last span, we had to break the median and guard rail in that area into segments. So, we would have to change the 3D model again. Finally, MoT agreed to leave the whole medians and guard rails as three objects, so there would be one median and two guard rails.

The new 4D model was built based on the revised schedule (Figure 46) and the new design issues. The problem with this 4D model was showing the micro simulation in the last span of the bridge (Figure 47; Snap Shots 3&4) .In NavisWorks, the user has to define just one speed and time interval for showing the process. Therefore, regarding the fact that making one span of the bridge is much lengthier than putting in one segment, showing the micro simulation with the same speed as the whole bridge would be too long.

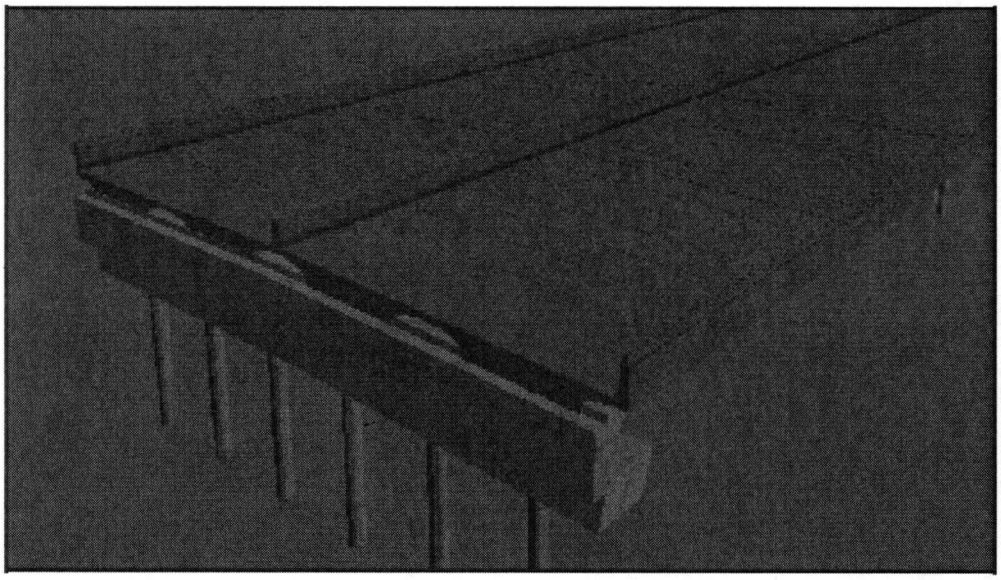


Figure 49: Final Micro Level 4D Model

Because of the duration time of each segment of the bridge, the speed had to be reduced to the lowest point. On the other hand, representing the whole construction process with this speed was much longer than it should be. In order to show the Micro 4D, we could change the speed and show the simulation in two parts. Also, we could make two different animations with different speed from the construction process. Then, link these two using movie editing software.

After all these changes, the meeting was held to see the result and progress. Although, the bridge and the road were seen in the space without any terrain or other objects, the outcome was satisfactory.

4.3.4 Methods Utilized to Enhance the Realism of the Model

Enhancing the realism of the 4D model in NavisWorks is much more difficult in comparison with the similar enhancement of 3D model in ADT. This is because of the fact that NavisWorks has limited properties and tools which can be used in improving the realism of the model. It was attempted to do as much as possible to realistically visualize the construction process in NavisWorks. In order to reach this goal, three sets of actions have been taken. The first one included simple and easy to do acts, while the other two consisted of some more complicated actions. The process of enhancement can be divided into three main categories: Materials and Colors, Terrain and Equipment.

4.3.4.1 Materials and Colors

In this section the process of adding materials and colors will be described. It should be mentioned that assigning materials in ADT was also possible, but because of the fact that when we exported the 3D model into 4D software, the texture and color of the assigned materials was changed by NavisWorks, it was preferred to assign the color and materials in the 4D modeling software. Also, it is possible to import materials or images of materials into NavisWorks and use them to enhance the quality of the model. Further, these materials can be edited in NavisWorks, in order to reach the suitable quality. Internally a material is defined by four shaders from different classes - Color, Transparency, Reflectance and Displacement. Each class of shader controls a different aspect of a material's behavior. There are many types of shader in each class, each type being defined by its own set of parameters. For assigning, editing, exporting and other material's related task, Presenter in the Tools menu can be used (Figure 50).

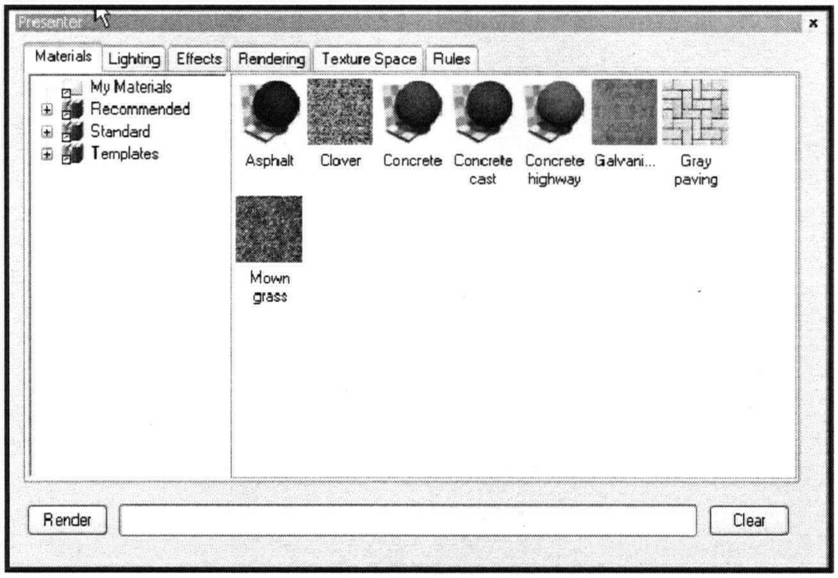


Figure 50: Presenter Toolbar in NavisWorks

Initially, more real color was added to the model, for example three types of concrete color were assigned to piers, segments and medians (Figure 51). Then, a layer of pavement was put on the deck (Figure 51). Also, materials were assigned to each segment in the 4D model.

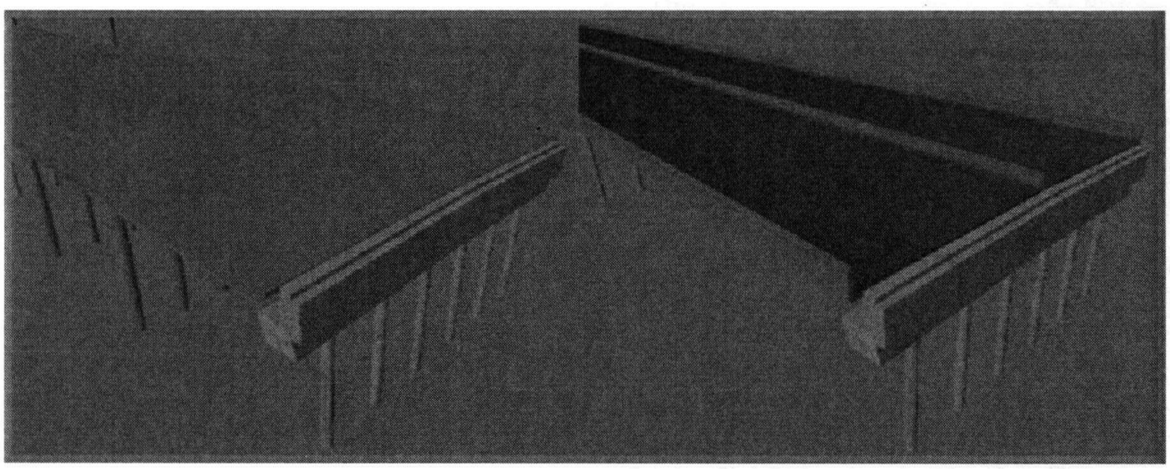


Figure 51: The Quality of Materials Used in NavisWorks

4.3.4.2 Terrain

The more complicated task, as was mentioned before, was adding the terrain to the 4D model. The terrain mesh was in the format of 3DS which was similar to Figure 30, which was the production of Visual Nature Studio (Section 4.2.4). So, it could be imported either in ADT or NavisWorks. The file size was big, and also during the export it was divided into 4 separate pieces.

The first task was to put these four pieces together. This task was done in ADT because of its several tools. Regarding the fact that the bridge had to be put on to this terrain, the position of the bridge was necessary to know. But there was no special sign in the terrain that could be used as a guide.

It was decided to import the image of the area of the project into ADT. The original picture type is ECW which has a huge size, but on the other hand has high resolution. At that time the plug-in for importing this type of image into ADT was not available.

The image which has the type that compatible with ADT was requested. The image file with TIFF format was received. The image was imported to the 3D terrain file, and after a challenging time we could match the scale and angle of the image to 3D terrain.

The main issue was the scale of these two different 3D objects. It was necessary to consider one of them as a base and change the other scale with respect to that. It was decided to change the scale of the terrain by using the "Scale" command in ADT.

Placing the bridge on its right place was also a challenge. In order to do that, lots of comparison between the image and terrain had to be made by switching between two ADT files with the same scale; one contained the picture and the other contained the bridge and terrain. Finally after lots of measurement, the approximate position of the bridge was identified. After putting the bridge in its position, the whole 3D model was exported to NavisWorks.

4.3.4.3 Equipment

In order to make the construction process more real and understandable, it was decided to add a crane to the model similar to the actual one that is going to be used in the construction of bridge. In order to make a simulation, it was required to know what kind of crane is going to be used during the construction. It was asked via email and the response was: "100 Ton crane with a vibratory pile driver has the reach and capacity for what this project requires."

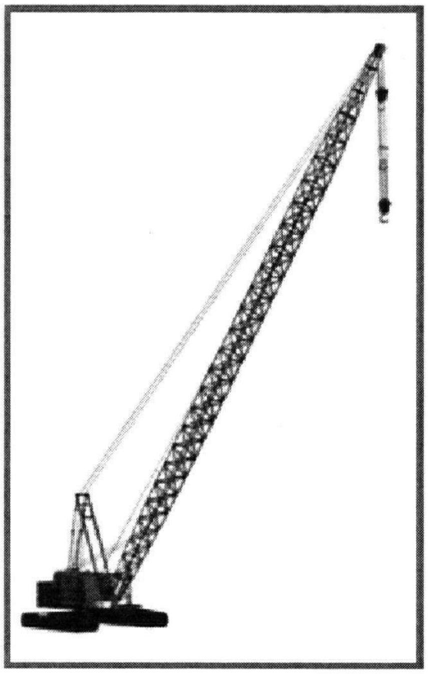


Figure 52: 3D Model of Crane

Since modeling this kind of equipment is hard and time consuming, it was decided to use available 3D objects. Unfortunately, a crane with a vibratory pile driver could not be found. I found a numbers of cranes and snapshots of them were sent to the designer, and the most similar one was chosen (Figure 52).

The next step was to import the crane into NavisWorks. For the micro-simulation of the last span of the bridge, it showed the way that the segments were placed during construction. I decided to add the crane to the whole process. The problem here was the fact that NavisWorks does not have animation properties like 3DMAX or even ADT. As an illustration, in NavisWorks you can not move an object by specifying the start and end point but it is possible in 3DMAX. The model of the crane had to be placed wherever it is going to appear, and then by playing with the schedule you can make them appear and disappear. This is what I did to make an animation or simulation process with the aim of showing the crane movement as construction progresses (Figure 53).

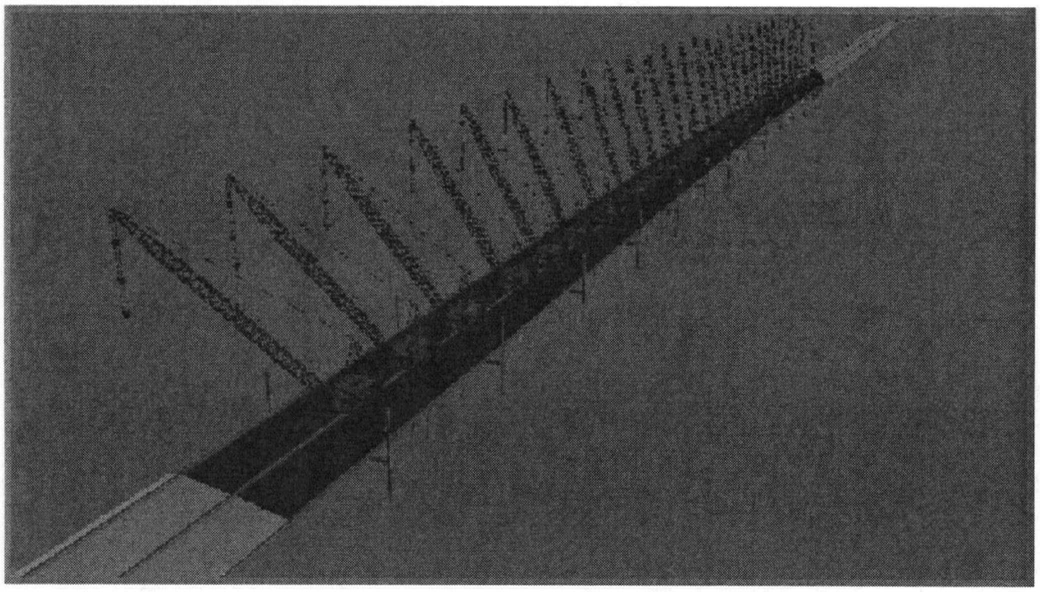


Figure 53: 4D Model with All Necessary Cranes

Some challenges were involved in the process of adding the crane to the model which is going to be discussed in the next sections. But the issue among theses challenges that relate to this section is putting the crane on the last span which already had a simulation for the segments. First, it was decided to move the crane along each row of segments along the bridge. It was impossible, because the crane models had to be put somehow over each other to make an animation, and we could not select the whole crane in NavisWorks when they over each other (Figure 54). Hence, I decided to put just one crane for the whole last part.

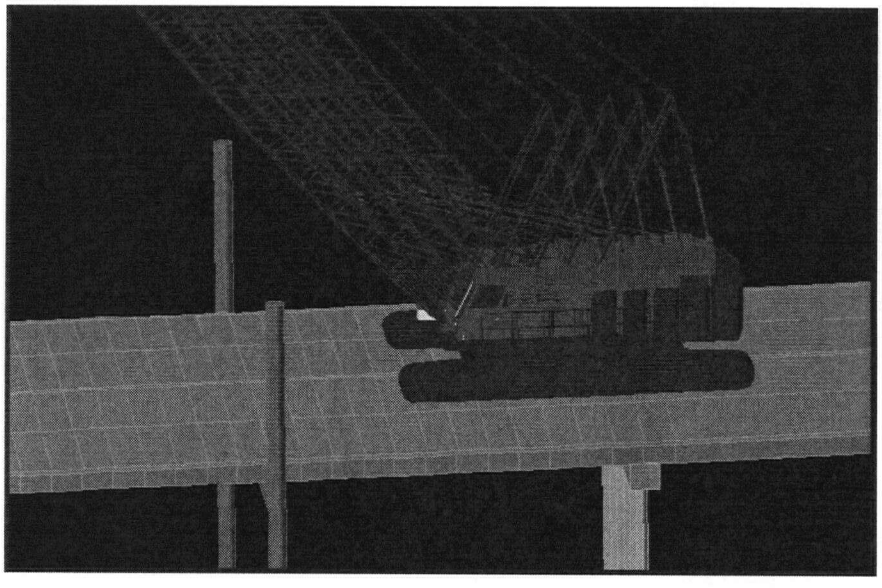


Figure 54: Putting Crane over Each Other to Make Animation for the Micro Simulation

Then the schedule and consequently the 4D model had to be changed. We had to add some fake tasks such as "Remove Crane" and "Add Crane" for animation of the crane in the schedule and made some necessary changes. The result was acceptable, although it is not an animation because the crane just appears and disappears in different positions (Figure 55). But it was good in order to show the position of the crane during the construction process, and to assess the properties of NavisWorks in terms of making animation.

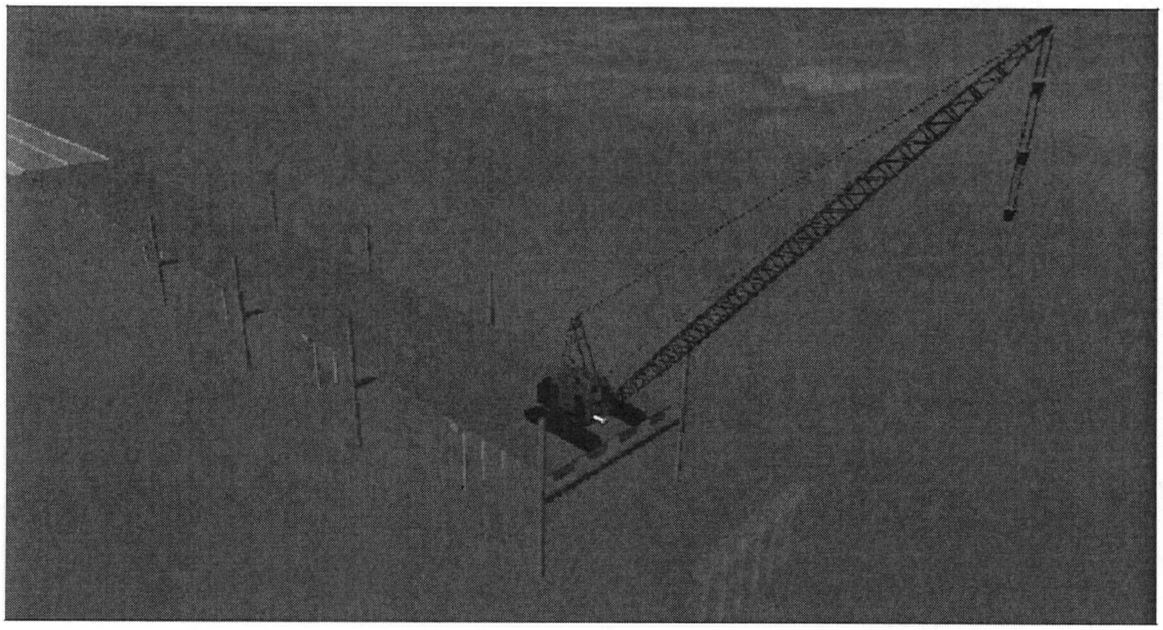


Figure 55: Adding Crane to the 4D Model

4.3.5 Critique, Benefits and Limitations

During the 4D modeling process, many points have been identified that can be categorized as advantages and disadvantages of the software which was involved in this procedure. In this section, I discuss and critique the 4D modeling software, NavisWorks, and also evaluate the usefulness of the models. Here again, it should be noted that this overview is based on the personal experience with the software during the project and does not necessary represent the exact capability of it.

4.3.5.1 Benefits

- NavisWorks gives access for all stakeholders to navigate, communicate and collaborate on 3D design models regardless of file size or format; offering a reliable way to challenge, check, mark-up and share the detailed 3D design.
- NavisWorks helped the designer to identify errors in the design for example, in this project, they changed the design of piers and temporary piers three times throughout the course of this project.
- NavisWorks provides improved 3D model handling with enhanced navigation, better process integration and powerful new features including streaming large models across the internet.
- NavisWorks 4D model helped Delcan to locate errors in their schedule, such as the tasks for removing the temporary piers.
- 4D modeling helped the client to understand the construction procedure and have a sense of the whole process.
- NavisWorks environment and file type allows the user to interact much more easily with the 3D/4D model in comparison with ADT.

4.3.5.2 Limitations

On the other hand, there were some difficulties or limitations with working in NavisWorks.

- One limitation of this software is the rendering capability. Regarding its limited sources for materials, colors and textures, it is difficult to represent the actual or real properties of those objects that are used in the 4D model. For example, in the project the texture of the materials which is in the software library or those that were imported are not good when it comes to rendering (Figure 51).
- Also, importing images with high resolution or special format like ECW is impossible. As an illustration, we tried to import the ECW image of the project because of its high resolution and quality, but we could not succeed.
- Moreover, when files that are supported by NavisWorks are imported all of the file properties can not be imported. I experienced this problem with the 3DS files

during this project. We tried to import a 3DS file which had colors and materials from VNS, but when we imported the file none of rendering properties were imported.

- Furthermore, if a huge file is used in this software, linking the tasks in the schedule to the related objects is a time consuming and error prone task. Because of the nature of NavisWorks editing the errors in the schedule and particularly the 3D model, can create lot of problems for the user. This was our main issue due to the fact that our project file consisted of many objects and elements.
- Finally, because of the fact that all objects in the software need to be linked to a schedule in order to produce a simulation, making a realistic animation can be considered as impossible. In certain cases even if an animation is produced, the quality is much less than the animations produced in other software, such as 3D Studio Max. This problem was obvious when we tried to make an animation of a crane in our project.

4.4 LESSONS LEARNED

During the course of this project many sets of software have been used. In general, about three bridges were modeled until the final 3D model was achieved. Further, more than five different 4D models have been produced before finalizing the last 4D model. Different visualization methods have been followed in order to enhance the quality and realism of the model. Consequently, many useful and practical lessons have been learned throughout our experience in using these software tools. Those practical lessons that have been experienced will be presented in this section. Also, this section can be considered as a summary of what we discussed before.

- The process of 3D modeling should be done by the constant connection with the designer and client with the aim of implementing their comments and changes throughout the design process and preventing any incorrect 3D objects. On our project, the relationship with the designer was not particularly good and caused rework for us many times.

- In order to make an efficient 3D model, the whole process should be planned beforehand. In other words, when a 3D model is being prepared for 4D modeling, all objects in the model should be classified and be put in the related layers, in accordance with the schedule and simulation process. Also, colors and materials should be assigned in the 3D model, although they will be changed after exporting to 4D software. The benefit of doing this is the fact that 4D software will consider a materials attribute for those objects that have materials. This is the result of constant work with 3D and 4D models during this project. This consideration optimizes the 3D and 4D modeling process. I experienced it especially when I had to import a crane to my model because of the fact that materials and colors were assigned to this model.
- The position of each object and the relation to other objects in the 3D model should be carefully considered before exporting to 4D software in order to avoid rework and unpredicted errors. I faced this problem when I ran the 4D model and saw that some objects did not connect to some of their surrounding objects or elements in a way that they should be.
- Scale and position of each object in 3D should be identified beforehand in order to have a realistic model. Also, it is advised to model all of the objects with respect to a main object for avoiding confusion in scale and positions. In this project a 3D line was used as the base for locating and scaling other objects.
- In 4D modeling, review the schedule thoroughly before connecting the task to the objects in the 4D model. This is important because finding errors in the schedule is very common, and finding them before running the 4D model can save time and avoid rework.
- With respect to convenient interaction with the 3D model in NavisWorks, it is advised to edit those errors in the 3D model that can be done in NavisWorks, and avoid editing in ADT because working with huge 3D models is much easier in NavisWorks. I faced this problem during updating part of the bridge in the project.
- Using different angles for viewpoints, utilizing flythrough or other tools in the viewpoint toolbar in NavisWorks can make the model more comprehensible and

also help the audience understand the 4D simulation more effectively. This was done for our 4D model in order to convey the construction process.

- In order to make an animation, it is advised to use other software because of the fact that 4D software has limited tools and properties to help a user make a considerable animation. This became evident when I decided to make an animation of the crane for the project.
- One of the major problems with this software is the rendering power and displaying the real texture and actual color of materials. Therefore, if the 4D simulation needs powerful rendering this software is not as helpful. This was experienced by comparing the result of NavisWorks and 3DMAX for our project.
- Although many sets of software have been used during this project, I could not explore all of the properties that they have to offer due to many constraints such as time. Therefore it might possible that some of the above points and problems were results of my lack of experience with these sets of software.

CHAPTER 5: CONCLUSION

5.1 THESIS SUMMARY

In this research the benefits and limitations of using 3D and 4D visualization tools in modeling virtual construction were illustrated through a case study. The case study was the Gateway Bridge Project which is part of the Gateway Program and was done as part of the University of British Columbia's Gateway Project visualization agreement with the BC Ministry of Transportation (MoT). Further, the information and necessary materials was provided by the Delcan Company representative during the course of the project as the designer of the bridge.

I made the 3D model of the bridge and part of the connection road by using Autodesk Architectural Desktop. Due to the change of design which was the result of environmental and geotechnical conditions of the project area, I had to change the 3D model of the bridge four times. Then, in order to enhance the quality of the model and make it more real, we imported the 3D model to the landscape visualization software, Visual Nature Studio (VNS), and by using its tools we added some other 3D objects to the model such as trees and houses. By using the properties in this software, the surrounding area of the bridge became more real. As another product of this software, a walkthrough file of the project area and the bridge was made, as well.

Simultaneously, in order to show the construction process, I made a 4D model of the project by using NavisWorks 4D modeling software, which was the result of connecting the 3D model to the construction schedule. Also, in this stage, because of the revision in the design and consequently changing the construction schedule, the 4D model had to be changed many times. Further, I added a crane to the final 4D model with the aim of increasing the reality of the construction process. Finally, in order to show more specifically what is going to happen during the construction of the bridge, I made the more detailed 4D model which was called Micro-Level model as opposed to the first or Macro-

Level 4D model. This model was made by changing the 3D model and schedule for the half of the last span of the bridge. It shows how each segment of the deck will be placed in its position. It should be considered that these two 4D model is in one file and in order to see the Micro-Level 4D model the speed of the animation should be reduced to its minimum.

We tried to import our VNS model into the 4D model software to use the high quality surrounding environment in the construction process animation which was the result of 4D modeling software, but we could not succeed. Also, we tried to use a third-party software (3D StudioMax) to do the importing but it was not successful either.

The models which were made during this research project helped the designer in each step of his thought process to see what they have imagined. Models also helped them to see the schedule errors by watching the virtual construction process animation. Also, it shows how using visualization tools can help all stakeholders of the project have the insight of what is going to happen, even those who does not have any construction background.

The visualization tools advancement is completely depend on computer technology development. Currently, due to some progress in computer industry, many visualization software tools have been developed that can be very useful in the construction industry. I tried to give an overview of all research and software development in the area of construction visualization in this research mostly in academic area, but with respect to ever changing technology, new tools will be born everyday. It is safe to say that construction industry does not utilize these tools very often in comparison with the wide range of available software even they can be helpful in various aspect of project from the beginning to the end.

5.2 CONCLUSIONS

With respect to the fact that construction visualization embraces various aspects in construction industry it was tried to provide an essence of what has been learned during the course of this case study project. During this research, the technology and use of visualization available to the construction industry were reviewed and investigated. The use of Virtual Reality and Construction Visualization is less prevalent, only companies working in specialized construction are more likely to look for innovative technologies in terms of software to increase their performance and effectiveness. Software packages in construction visualization and virtual reality software has been found to be very useful in training workforce in specialized construction

There are many state of the art software tools and computers available in the market but every construction company does not need every thing that is available. This decision is based on some factors that rule the company's financial strength.

One of the main reasons of using visualization to design construction operations is to posses an insight into different designs and therefore helping the planner make the most effective decision. Recent advances in computer software and hardware technologies provide an unheard of opportunity to the construction industry to continue the implementation of more efficient and effective design and construction process to facilitate the integration process. Construction visualization has the potential to change the construction industry by producing faster and less expensive design and construction processes with better quality in advance of the project in order to find probable problems and mistakes.

3D CAD software has become a minimum standard in construction industry replacing 2D CAD software. Project schedules can be combining with 3D CAD models to generate 4D CAD models where fourth dimension is time. Projects can be comprehended in computer animations as project schedule advances which is particularly helped in finding and locating design and construction interference along with other bottlenecks. Also, 4D modeling helps to better evaluate the construction schedule in order to prevent any practical and logical errors while it is obvious that logic errors easily identified in the animation environment.

Recently, CAD-based animation has been developing very rapidly, and is becoming a more economically viable and powerful tool. In many engineering field including Architecture, Electrical and Construction, 3D CAD modeling systems are being applied and implemented at different levels.

During this project, the results indicated that using CAD-based visualization during planning enhances the scheduling process by reducing missing activities when extracting them, and finding forgotten relationships when developing them, and finally decreasing invalid relationships in the schedule. Moreover, CAD based visualization of the planned project help inexperienced schedulers in the area of developing valid activity relationships, and helps them to develop a schedule more effectively.

3D CAD based visualization mitigates many of the inefficiencies of the traditional two dimensional drawings. Some of the 3D CAD modeling benefits in visualization include: eliminates the mental effort of transformation step from 2D drawings to 3D images, provide everyone a consistent view of the final product, allows the object to be viewed from any angle, can be viewed at different scales and with different level of details depending on various user requirements, combine and centralizes several sources of information, and provides the ability to view 2D plans and elevations.

Graphically animating the construction schedule (4D CAD) has advantages which include: quick perception of physical geometry, understanding complex information, enabling owners to get involved and appreciate the complexity of the work, potential as powerful learning tool for the construction process, enabling the testing of alternative schedules visually, and providing the sensing of space requirements activities and storing materials

In terms of landscape visualization, pictures in the form of realistic landscape visualization have proven to be highly successful in allowing all stakeholders of the project and those who do not have any construction knowledge to engage in important aspects of the project, construction issues and impact to the land at a highly localized scale. This ability to enhance the visualization of the future terrain effects of resource management proposals using photo-realistic imagery and 3D completed models may provide an essential medium for land-use planning and landscape design processes involving different communities.

But on the other hand it should be considered that in order to have a realistic landscape visualization digital elevation and aerial imagery data is necessary and it is just readily available for United States and some other parts of the world and this data is archived in several different digital formats at varying levels of detail. Therefore it can impose limitations for projects in some parts of the world in terms of landscape visualization.

The novelty of using visualization in construction industry was the driving force in this research. In this case study we tried to represent the potential benefits of using visualization techniques in helping the planners to investigate their plans and schedule before starting the actual construction, in order to find the errors and mitigate the risk, and fortunately the result was satisfactory.

5.3 FUTURE WORK

This research for construction visualization using 3D and 4D models may be developed in different ways. As an illustration, a research on visualization methods able to clearly represent the interactive impact between design changes during the project and performance seems to be necessary. Moreover, the future research can provide a frame work to implement planning and process design start from a macro level, propagating to lower, more detailed (micro) levels into construction visualization process, and assesses the value of that in the project planning and design process.

Assessment the impact of 4D visualization on enhancing the insight of project participants, crews' learning curve, and stakeholders understanding of the project, can be another area of research

Extending this research to other kinds of construction visualization requires further study. For example, modeling the real world construction situation, such as weather and climate change or showing the exact operation of construction equipments such as driving a pile which makes the visualization model more similar to real construction process can be another area of study. Also, trying to integrate various properties of powerful sets of software together in order to have more tools to simulate and visualize construction process and provide more realistic model.

Regarding the advancement in computer games and animation movies, in terms of life like simulations and characters, and also the tools that have been used in producing them, trying to find a feasible way to use and integrate this technology in construction visualization can be another potential work for researchers.

Due to the fact that implementation of new technologies have always been the major problem in adopting them, and also in the past the main challenge was cost, it is now more organizational and human issues that stand in the way of taking full advantage of the benefits that can be realized. A research approach can be devoted to solve this problem.

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