

# **Construction Planning of a Railway Bridge Using the Concept of 4D BIM**

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## **ABSTRACT**

Between the world industries and in the slight past decades the market of the Architecture, Engineering, and Construction (AEC) industry was decreasing from a quality of producing and execution point of view. A new rising concept appears lately to help in solving this dilemma, Building Information Modeling (BIM) was that concept with the new dimensions methods. The fourth BIM dimensions (4D BIM) is used for the method of this research to monitor and control the construction processes with the time factor. The result obtained from the analysis to show the positive and negative points related to the 4D BIM tool. Three software had been used in the method of this research: Autodesk Navisworks Manage 2014, Autodesk Revit 2014 and Microsoft Project 2013, helped lately after finished from the methodology for a railway bridge CAD drawing obtained from Saudi Arabia that this software satisfied most of the construction management`s requirements. Plan visualization and model simulation was done for the railway bridge since it was the purpose of this study to find and understand the difficulty related to the infrastructure with the 4D BIM.

**Keywords:** BIM, 4D, Saudi Arabia, railway bridge, visualization, simulation.

## ÖZ

Dünya endüstrisi arasında, Mimarlık Mühendislik İnşaat (MMİ) endüstrisindeki pazar, üretim kalitesi ve yapımı açısından son on yıl içerisinde azalmaktadır. Yapı Bilgi Modellemesi (YBM) yeni boyut yöntemleri olan bir kavramdır ve yeni yükselişte olan bu kavramın son zamanlarda bu zor durumun çözülmesine yardımcı olacağı görünmektedir. Bu araştırmada yapım sürecini, zaman faktörü ile birlikte denetlemek ve kontrol etmek amacı ile dört boyutlu YBM (4B YBM) kullanılmıştır. 4B YBM aracı ile analizlerden elde edilen olumlu ve olumsuz sonuçlar incelenmiştir. Bu araştırmada, Autodesk Navisworks Manage 2014, Autodesk Revit 2014 ve Microsoft Project 2013 yazılımları kullanılmıştır. Suudi Arabistan'daki demiryolu köprüsünün CAD çizimleri tamamlandıktan sonra, bu yazılımın son zamanlarda birçok yapım yönetimi gereksinimlerini karşıladığı görülmüştür. Bu çalışmanın amacı olarak 4B YBM altyapısı ile ilgili zorlukları bulmak ve anlamak için demiryolu köprüsünün plan görselleştirilmesi ve model simülasyonu yapılmıştır.

**Anahtar Kelimeler:** BIM, Suudi Arabistan, demiryolu köprüsü, görselleştirme, simülasyon.

## **DEDICATION**

This research is dedicated to my dear parents Mr. Mohamed A. Dirweesh, Mrs. Batol Hashim, my brothers Dr. Ahmed Dirweesh and his family, Mr. Hashim Dirweesh, to my company Freyssinet SA. (Especially to Eng. Fayez Abaza) and last but not least to all my friends who support me during this journey.

Thank you all...  
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# Chapter 1

## INTRODUCTION

### 1.1 Motivation

Building Information Modeling (BIM) was found in the 1980s, and it has been used specifically as the process itself and for the BIM tools performance by that time was matured and related to enhance the computing. Now both information transfer and software in different stages consider as concerns in many domains. 4D BIM tools used by engineers mostly for creating BIM models. Problems related to railway bridges still existed when the concept of 4D modeling involved.

All types of bridges in Saudi Arabia today were presented as 2D drawings, so in order to obtain a full and clear overview for the project stages mostly done was by combining several 2D CAD drawings together. It's faster and easier to have a better visualization and overview by applying the concept of 4D BIM Modeling.

### 1.2 Background

#### 1.2.1 Building Information Modeling (BIM)

BIM is an abbreviation for Building Information Modeling. This abbreviation meaning had been obtained directly from the context. Engineers, companies, or even the organizations have described the BIM in various concepts. However, the definition or the concept related to The National Building Information Model Standard Project Committee was clear and understandable to lead those concepts as:

“Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward” (National BIM Standard Project Committee, 2012).

Some people can argue about the expression of “shared knowledge resource” if it’s suitable to use it here as a right depiction, users can always obtain and develop their knowledge by using BIM as a resource for that. People may discuss about the gained knowledge through the gate of BIM; yet BIM consider as a portfolio for a possible knowledge. The letters I for Information and M for Modeling are very significant in the BIM perspective; by creating a full model for the project with all the outputs provides from it in one file and easy to access to those outputs from any one of the staff who related to that project. Dealing with BIM gives a unique advantage to anyone involved in the project like owners, architects, engineers and contractors to add there adjustments, notes in different shapes (architecture plans, structure plans, cross sections and material lists). The BIM tools consider very strong and effective comparing to the existing ones, these tools connect all the people who work in the project with the same information extracted from BIM models in a powerful ways.

The 4D model that can be prepared using the BIM tools gives a strong relation between the project objects that cannot find in the traditional ways (CAD tools) where all the drawings are separate from each other. For example once an object is modified or replaced in the model, it will be replaced everywhere in the BIM, which consider more efficiently than the traditional ways.

### **1.3 BIM in Infrastructure**

BIM in infrastructure had many difficulties and reasons preventing from applying it in this sector:

- Customers have no interest or demands regarding to BIM.
- The use of CAD tools in this sector consider almost successful; so there is no need for BIM.
- Using new software usually takes time for companies staff and it`s always considered as cost consuming because of the replacement of the old system or the processes by the new ones.

And yet the technology that brought by BIM contains some flaws and problems, like in non-standard geometry. Cast in place concrete is an example for that specifically when it comes to railway bridges. In AutoCAD as an example for the programs that are not differentiate for BIM use, transact a works with these flaws in an excellent techniques and methods to produce and to generate a geometry in a correct ways.

However, for the benefits of applying BIM in infrastructure sector some softwares had been used for example Autodesk Revit (3D Modeling) or Autodesk Navisworks (4D Modeling). These models were proving that for any complicated projects there is a faster and easier way to model it using the concept of BIM.

### **1.4 Scope and Objectives**

The aim of this study is to show the benefits gained from using the concept of 4D BIM in railway bridges, by using a 2D CAD drawings from Saudi Arabia to generate a 3D model using a BIM tool; then transfer this model to a 4D BIM model by importing the construction plan related to that model elements.

The objectives from this research are:

- Adding new knowledge by developing a construction plan for a railway bridge in Saudi Arabia.
- To support the use of BIM planning for a faster sequencing and accurate visualization.
- To understand the challenges related to railway bridges when it comes to BIM.

## **1.5 Why Saudi Arabia**

Saudi Arabia being considered one of the largest countries around the world, has been developed widely in many fields and sectors especially in infrastructure. Railway networks represent a large part of that sector and the revaluation related to railways was not only nationally but also in the major cities in an impressive way. Saudi Arabia have a large number of multinational construction companies which resident in it, and yet most of these companies use the traditional ways as CAD tools for example to satisfy the owner requirements. Railways in Saudi Arabia is taken under the authority of Saudi Railway Organization (SRO). The concept of applying BIM had been used before in Saudi Arabia for building projects. In infrastructure, nothing has been made yet regarding to use the BIM tools. Country with that size should definitely change the methodology of using two dimensions representations for the projects to 3D or 4D BIM models.

## **1.6 Methodology Outline**

2D full drawings for a railway bridge was brought from Freyssinet Saudi Arabia Company to create the required 4D BIM model related to this study. Transferring of this drawing to 3D model was done using BIM tool (Autodesk Revit 2014), and construction plan was made depending on the created model elements with a suitable sequences.



The 3D BIM was exported into 4D BIM tool (Autodesk Navisworks Manage 2014) which was the suitable tool to work with. Then the construction plan was also imported to the 4D BIM tool. Furthermore automatic links were created to connect the model elements with the activities to generate the required 4D BIM model for the railway bridge. Visualization and simulation was played as an advantage for the 4D BIM tool in order to check and test the model effectiveness.

### **1.7 Outline of This Study**

This work is grouped in five chapters, the first being the introductory part. Chapter 2 is the literature review, which covers a brief history of the construction planning steps and methods. It also covers introduction for BIM, dimensions in BIM and methods of creating 4D BIM model. Chapter 3 presents the methodology used in this research, characterization of the research software, and generation of the 4D BIM model. Chapter 4 involve results and discussions of the analysis and running for the 4D model, with the evaluation for the 4D BIM tool and comparing it with traditional planning methods. Chapter 5 covers the positive and negative points for the 4D tool when it comes to infrastructure, also the upcoming challenges and recommendations.

## **Chapter 2**

### **LITERATURE REVIEW**

#### **2.1 Planning in Construction**

Gradually, construction planning represents a big value in development of the construction sector (Allen & Smallwood, 2008). Construction planning gives an overview for the project depending on the activities' sequences for that project. It considers as a hard mission for the planner to deliver that overview because none of the activities had been done yet in this stage of the project (Hendrickson, 2000). Additional to that, the inescapable nature of incertitude and complication related to the construction projects gives some difficulties for the project team to achieve reliable plans when it comes to construction (Huang et al., 2009). Zanen and Hartmann (2010) referred to the value of preparing an early plan before the start of construction stages; to determine the future errors for the project, taken actions to fix this errors and to identify the required crews which will give the highest proportion of success depending on that tasks in the plan. Yet, the concept of construction planning should not be related only to the early stages of the project; it should also have a place in the project lifecycle because some changes may appear later requiring a re-planning (Hendrickson, 2000). Efficient and well-made plan not only can show and determine the potential errors, but it also reduces and reverses the results of such errors (Zanen & Hartmann, 2010).

The purpose of creating a plan is to make a list of the required activities showing the relations between them and that way to guarantee and limit the work within the safety, environment and economical sides during all the stages of the project from start to end (Zanen & Hartmann, 2010). Mainly, the construction plans connected to the identities for the main activities which usually take the projects to their final result. Analysis need to be done by the planners, for the activities, procedures, and the effects of these activities. Subsequently, a study for the former projects using the expert judgment, final conclusions will be drawn containing the most effective methodology required to deliver the work. In construction planning all the tasks are specified, resources are allocated and the parts involved in the project with the relations between them have been fixed (Hendrickson, 2000).

### **2.1.1 Construction Planning Steps**

The processes of creating plans is critical, and also it's an important part in construction. Planning process is complicated and contained many procedures. Figure 2.1 briefly shows all the workable procedures required for creating a construction plan.

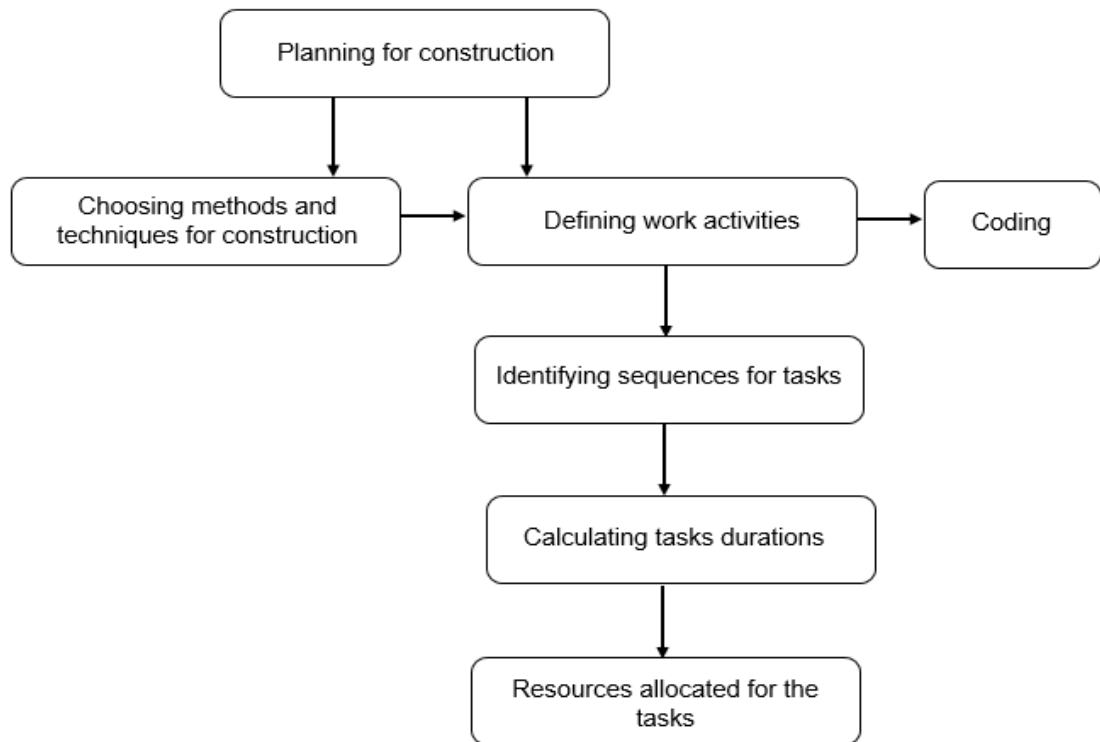


Figure 2.1: Workable Procedures in Construction Planning (Hendrickson, 2000)

Choice of the methods and techniques for construction are the two initial workable steps to define work activities which can also be done at the same time. Choice of the methods and techniques for construction can have a full effect in the project. Hendrickson (2000) proposed that carefully consideration for the staff experiences and capabilities should be taken by the planners. He also suggested to create a construction plan depending on the selected method and technique in order to evaluate this method with the alternative ones for the projects.

Identifying the work activities helps all the project staff to understand the activities involving in project delivery. In this stage of construction planning all the tasks will be connected and allocated to the resources. Commonly, these work tasks are modified during the planning stages and ended in a shape of hierarchical framework. Simple or

complicated list of activities can be important and effective in the project so the planners must have a wide view for the project (Hendrickson, 2000).

After defining the work activities, the suitable duration should be evaluated by the planners if it's acceptable or not and this duration contains an extra time if any delay may happen later. Usually in many of the cases, this evaluation depends on the review of similar former projects or on the expert judgment for the planners. Definitely, each project is different from the other and that's why these tasks cannot be identical with each other, and here when the planners skill take place on the stage (Hendrickson, 2000).

Throughout the construction scheduling, the resource related to each activity should be allocated which is considered as a critical step. During this step, the equipments needed, the number of crews (depending on the productivity), required materials and just like that, the cost related to any task could be found (Hendrickson, 2000).

Further to that, since the construction planning include tons of work tasks, the idea of writing each activity in its full descriptive words make the plan complicated and hard to follow. This idea usually is avoided by the planners using a concept of coding method when the long description can be replaced by brief and elegant numbers system. Plus, this concept of coding method increase the efficiency of data flux and guarantee the stability of different elements in construction projects (Hendrickson, 2000).

## 2.1.2 Some Methods Related to the Construction Planning

During the improvement of construction industry, many and multiple methods related to it have been used to create plans related to the construction such as Critical Path method, Gantt chart method, and Linear Based Scheduling method. The following section will focus on a brief view for this methods and a quick look for the advantage and disadvantage for them.

### 2.1.2.1 Gantt Chart Method

Henry L. Gantt developed the Gantt chart as a time schedule, a forerunner who started using the methods of management scientific for the construction processes. Gantt chart found many differences of the shape and implementation based on the works field (Nunnally, 2007). Figure 2.2 below illustrates a sample for a Gantt chart schedule.

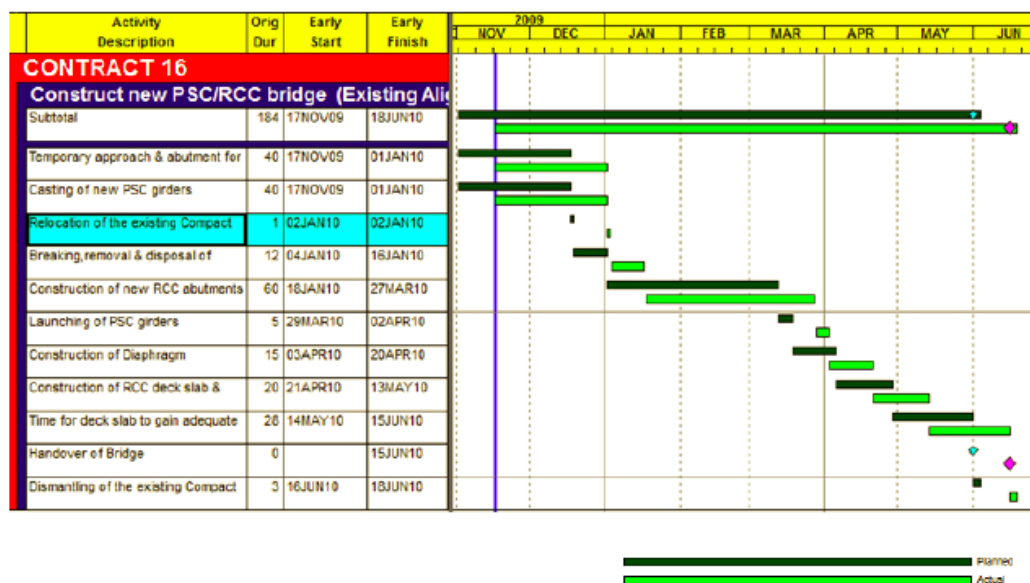


Figure 2.2: Sample for a Gantt chart Schedule (Dang et al., 2012)

From Figure 2.2 above, it is clear that the Gantt chart characterizes the activities and durations related to it according to the scheduled plan and effective performance. In these days, Gantt chart is still active with a big publicity back to the advantages that it is simple to use and easy to perform with. Yet, Gantt chart has disadvantage point

when it comes to the relation between the activities. It's hard and almost impossible to use the graph schedule to specify what is the most important activities. Thus, Gantt chart is not actually helpful for the project staff to determine the influence of the change or delay activities on the rest (Nunnaally, 2007).

### **2.1.2.2 Critical Path Method (CPM)**

In 1957-1958, large development in creating plans guided to establish the CPM. With higher standards than the Gantt chart method, CPM was not related only to the project required of the tasks. This method involves explanations and clarifications about the relations between those activities. For suitable design using the CPM, certain steps are required. Work Breakdown Structure (WBS) need to be prepared with all the required tasks, and assessment for the tasks end time and defining of the activities intersect (Santiago & Magallon, 2009).

Andersson & Christensen (2007) pointed out that CPM is incapable with resource chains to cope regarding to the works tasks. Where CPM assumes that resources are unbounded for construction of works, but that claim wasn't actually correct in the actual life. And for that reason, it's easy to predict if there are any lack related to the resource of the project or struggle in the tasks regarding to the use of the project resources (this issue will revise a confusion in construction stages and therefor the activities delay can be inevitable). More than that, CPM fails to act and explain with a certain types of activities especially in site works where the same tasks could be done in separate places under mutual times.

### **2.1.2.3 Linear Scheduling Method/Location Based Scheduling (LSM/LBS)**

In the early 1950s the linear scheduling method (LSM) or the location-based scheduling (LBS) have been created (Andersson & Christensen, 2007). LSM usually used in construction sectors like railways, small buildings, highways and high-rise

towers. This method allows the planners to stay away from generating schedules that can create struggle between the tasks and activities and to make sure during the project life cycle about the unceasing of the resources working (Nunnally, 2007). Still, the performers of the construction did not get that attention from the linear scheduling method. And that can be strongly related to the difficulty in changing any input level after it is fixed in the schedule. In the first stages of scheduling the software related to linear scheduling method needs a huge quantities of the information (Andersson & Christensen, 2007). Figure 2.3 gives an example for that method.

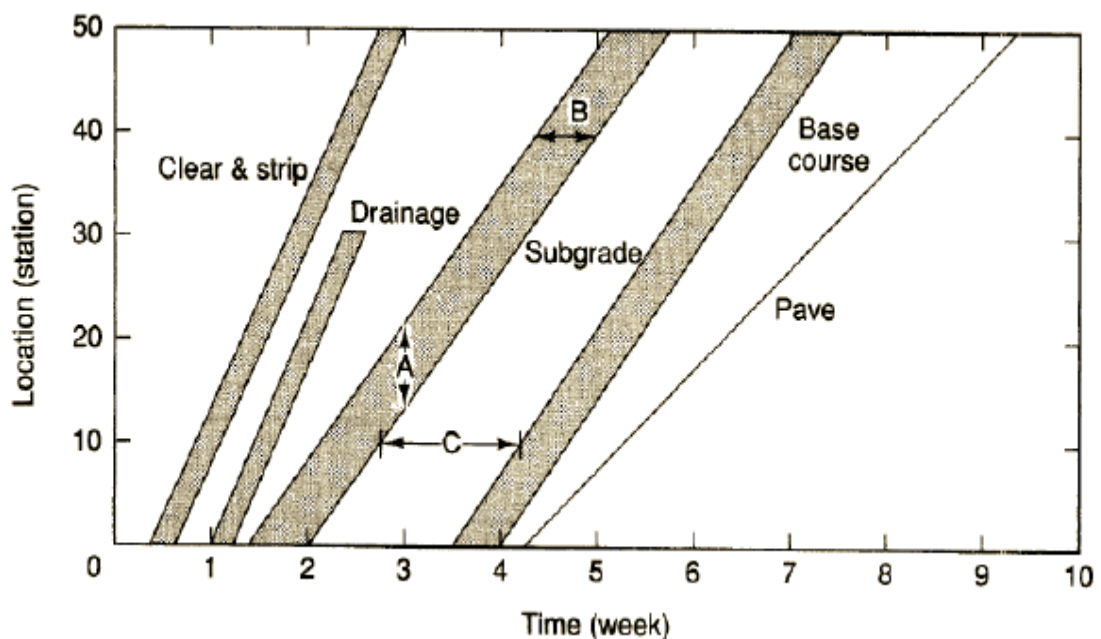


Figure 2.3: Sample for Linear Scheduling Method (Nunnally, 2007)

## 2.2 Concept of 4D BIM

### 2.2.1 Introduction for BIM

BIM can be considered as a big evolution in the recent years. This evolution is created by cooperation between engineering, architecture, and industries of construction. BIM generates digital virtual models of a building or highway mostly. The computers used to create the models have a delicate geometrical information for the project elements



with some other required information helping to enhance the procurement and construction tasks. Some functions should be available to model a building or a bridge in the full life cycle. BIM covers all this functions to create new principals for the construction ability and design. While the effectively used, BIM give a smooth and more combined design and construction steps which effect the projects' quality by reducing the cost and decreasing the time (Eastman et al., 2011). By 2010 BuildingSMART defended BIM as:

“BIM is a group of data which is organized in a certain concept to give the advantage of information sharing. BIM represents the project as a numeric model containing all the data related to it in one model”.

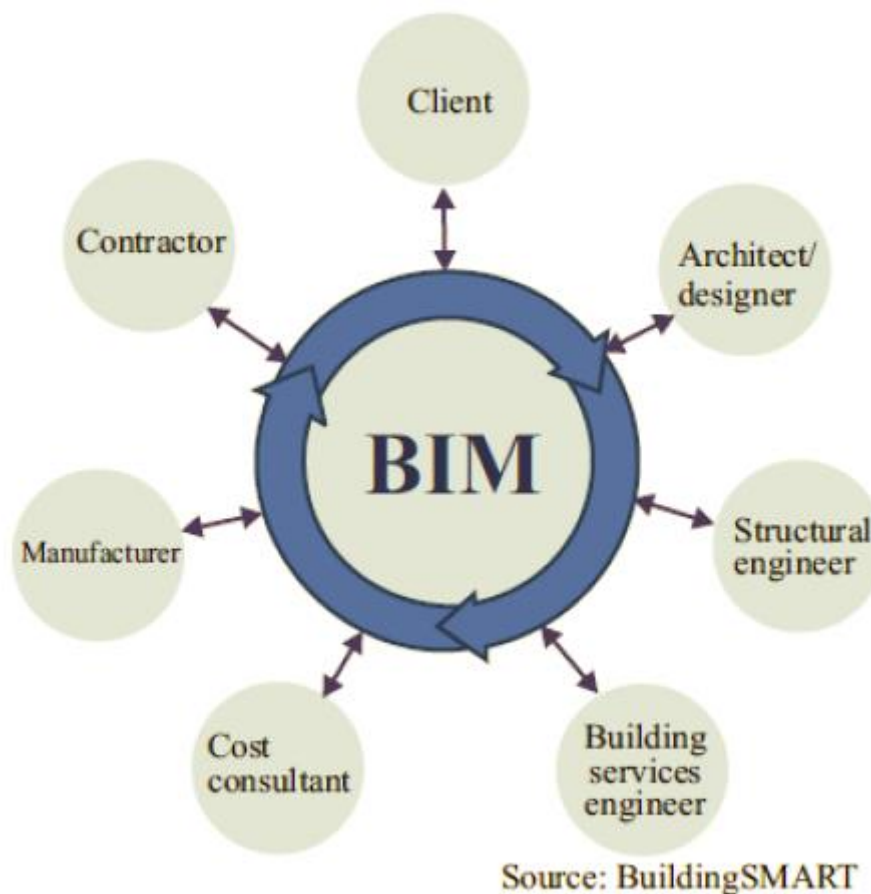


Figure 2.4: Stakeholders Related to BIM (BuildingSMART, 2010)

The purpose of BIM is to enhance the relationship between stakeholders as shown in Figure 2.4. Also its aim is to decrease the documentation time required for the project and provide more future expectation regarding the outcomes of the project. BIM has huge power as an information holder in the project (BuildingSMART, 2010).

### 2.2.2 BIM and related functions

BIM with complete functions can easy incorporate with many other functions depending on the projects specialty and requirements as seen in Figure 2.5. BIM can be involved and used for a functions group list. So much information can be collected and gathered from these functions related to BIM (BuildingSMART, 2010).

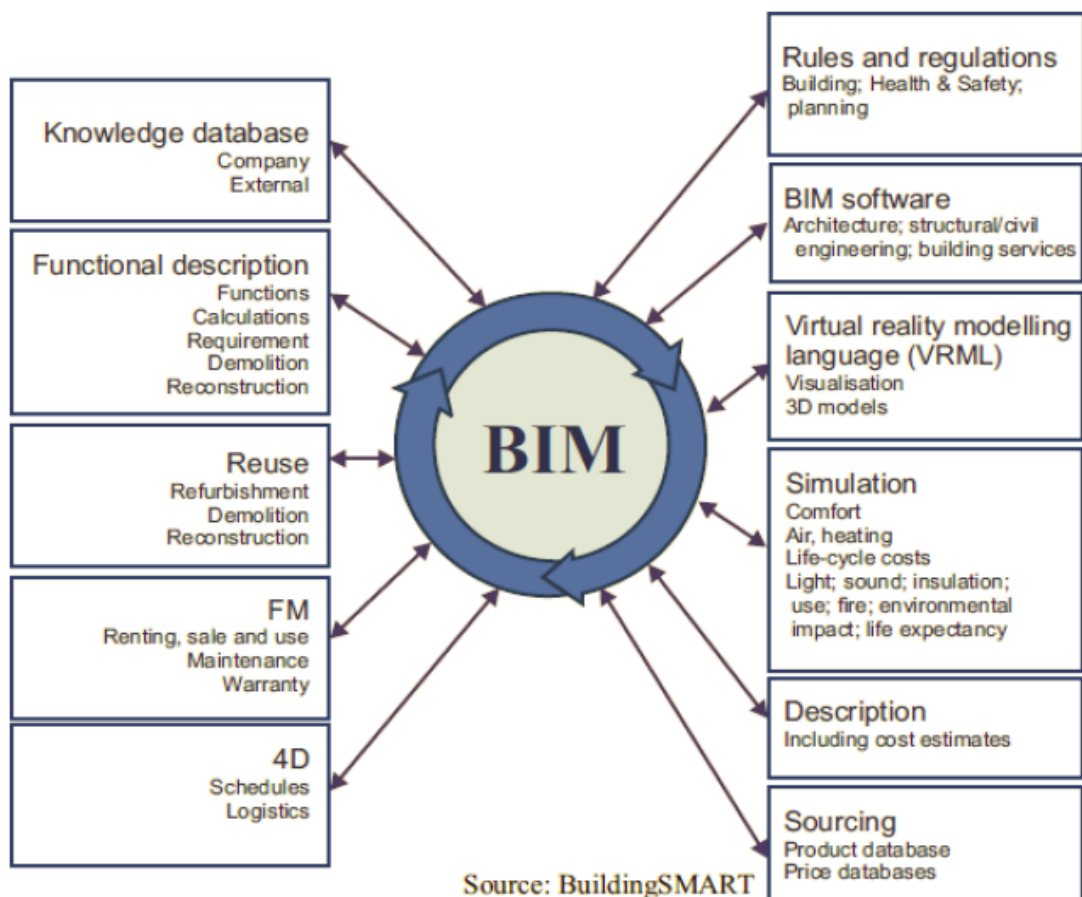


Figure 2.5: Building Information Modeling and related functions (BuildingSMART, 2010)

BIM is usually used from the beginning of the initial stages of the project, in scheduling stage and to examine if the project stratify with the rules until different phases of design in the project. BIM Stakeholders (architectures, structural engineers, etc.) mostly perform their work in fast and easy way using one of the software that serve BIM. Those softwares related to BIM can create a 3D model for the project even before the site work start. Design can be enhanced and the cost outcomes can be extracted after BIM come in with extensive analysis and functions performs. Above on that, for more beneficial planning and scheduling, activities durations as a time dimension for the project also can be interest to BIM. During the operations and maintenance stages for the projects, BIM can be very useful to the operators (BuildingSMART, 2010).

### 2.2.3 Dimensions and BIM

BIM dimensions were divided into three as following: 3<sup>th</sup>, 4<sup>th</sup> and 5<sup>th</sup> dimensions, where 3D is a third space dimensions; 4D gained by adding the dimension of time; and 5D contains the dimension of cost (Kymmell, 2008). Figure 2.6 below shows the BIM dimensions.

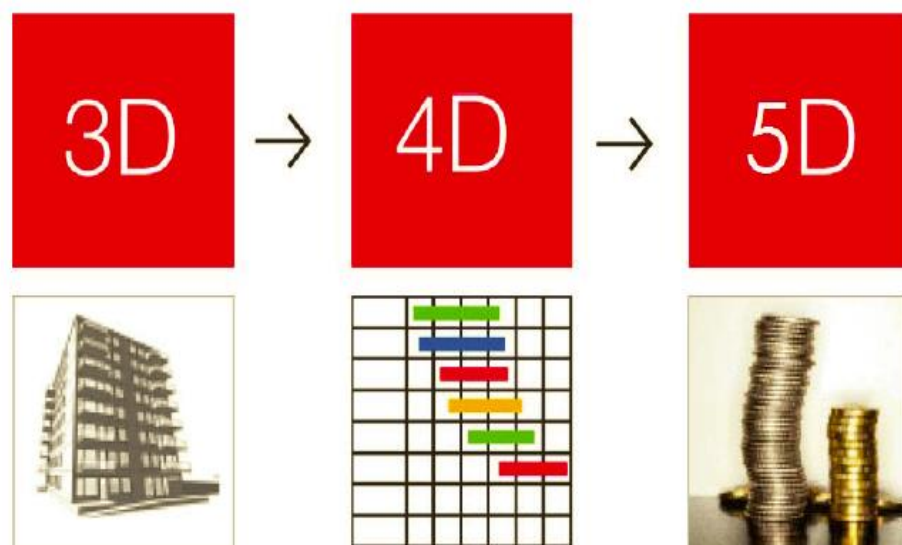


Figure 2.6: BIM Dimensions (Dang et al., 2012)

### **2.2.3.1 Third Dimension in BIM**

BIM 3D dimension involve the geographic data, geometry and locative relationships as example: the height, width and length of the project elements. The design fallacies that produced from the 2D drawings can be discovered and taken away using the virtual model of 3D BIM. Adding to that, a comparison between different models can be done to clarify if there is any errors or issues before construct them on site. By creating a 3D model and ameliorating the relationship between the projecting actors, the fallacies of the project can be improved and decreased in an enormous way. This guides to an effective projects especially in construction stages with low cost and probably less lawful odds (Eastman et al., 2011).

### **2.2.3.2 4<sup>th</sup> Dimension in BIM**

By connection the 3D model to the time dimension (construction plan) a 4D BIM model will be created, adding the factor of time to the model gives a typical simulation to the reality which provide a new information related to the construction stages and the time for it. Planners can use the space and time as a factors to create an activities plan and they can connected visually using the concept of the 4<sup>th</sup> dimensions BIM. (Eastman et al., 2011). The rate of data production can be added into the stage of the construction which will allow by balancing the plan to have permit line scheduling. This gives a new categories for the activities depending on their location and performance on site. A considerable change in the project performance can be done by creating enhance in the rate of data production and continues activities (Kymmell, 2008).

### **2.2.3.3 5<sup>th</sup> Dimension in BIM**

When the cost is linked to the 3D BIM model, a 5D BIM will be created which gives the possibility of following the cost at any point in the project stages. And it can also be used to set the budget limits in the first phases of the project. During the development of the model, new inputs and outputs data will appear which will improve and help in the budget estimation. 5D modeling can be very helpful in the comparison between the site performance and the project planned budget and that can be done by gathering the outputs cost for the model (Kymmell, 2008).

### **2.2.4 Planning for 4<sup>th</sup> Dimensions in BIM**

The concept of planning includes defining the activities and scheduling and linking them with suitable sequences depending on their durations and the space, allocating for all the required resources, determining the procurements, and other requirements related to the planning phases. Traditional methods (Bar charts, CPM) are capable to define a plan for the works tasks. Yet, these methods cannot categorize those tasks or even connect them to the project model. And for that, the process of scheduling can be hard to make it manually and it usually does not reach a full concur with the related design, so the plan is mostly complicated to the owners to follow and it may have an influence in the construction sequences. To avoid these errors and fallacies in the project planning, a 4D BIM has been created. With time a lot of tools have been developed to smooth the way of producing a 4D BIM model connected to 3D geometry model automatically. BIM tools allowed the scheduler to produce, analysis, and upgrade the 4D models with widely efficiently, this has consequences on the applying of other credible and related schedules (Eastman et al., 2011).

4D BIM modeling creates a realistic simulation for the project plan and gives the users the possibility of evaluating that plan. Categorizing of the elements in the project

model must depend on the construction stages and connected to the related activities in that project plan. As an example, if a column will be casted in two different times, then the element representing that column must be clarified as two parts so that the planned sequence can be more clearly explained and be reliable. Adding to that, the temporary tasks like entrance signs, tower cranes and scaffolding should also be covered in the project model. In creating a 4D BIM model for planning stage, the contractor feedback is very important. During design stage, if a 4D BIM model is created, the contractor can help to develop that model by sharing his experiences to establish a project methodology, listing the proper works tasks and the sequences for them and also in the cost estimation. BIM 4D modeling develop a project plan which can work as a hunted tool to catch all the expected errors and as a technique to enhance the relationship between the project actors (Eastman et al., 2011).

#### **2.2.4.1 Methods of Creating a 4D BIM Model**

There are several ways and methods can be used by the planners to create a 4D BIM models as shown below:

- 2D/3D BIM tools non-auto method.
- 3 dimensions BIM tools to 4 dimensions (built-in method).
- Transfer both 3D model and construction plan to 4D BIM tools.
- The use of 2D/3D BIM tools non-auto method

This method has been used for years by planners with the idea of using different pencils colors with drawings to show the sequences between the activities and the evaluation of the actual work against time. Later on, this method was improved from hands drawings to computer-aided design (CAD) tools. A third party is usually involved in this method when it comes to the current plan visualization to help produce in the

animations. The use of the animations gives an attractive visualization and it is good for marketing, but still they are unsuitable tools when it comes to planning. The use of the animations in this method can be related mainly to the availability of a few options only for updating and changing the schedule in preparing it manually. The use of manually creating requires an intensive work from the planners if any change happen in the plan. This intensive work usually is done by preparing new animations collection and manually trying to adjust the 4D animations with the plan. Therefore, the idea of using this tools or method is limited mostly to the design first phases when the owners are much interest in the project visualization (Eastman et al., 2011).

- 3 dimensions BIM tools to 4 dimensions (built-in method)

4D animations can be created also using the BIM tools. Revit for example have the advantage of elements filtering in the 4D model view. This advantage in Revit can divide the selected element into many phases depending on the requirements. This kind of 4D implementation is appropriate for the requirements in the 4D animations and initial stages, yet it does not gives any straight conjunction with the work schedule. On the other hand, by using other BIM tool, the feature of scheduling built-in provided by Tekla Structures can allow numerous connects between the model activities and corporeal elements. One or more activities can be connected to one corporeal element and also many corporeal elements can be connected to a single activity which makes the 4D valuation for the project sequence is able to be done, with show and hide of temporary means. The need for insert-on tools requires a lot of BIM tools since the advantage of “date” or “time” built-in is not available, and it`s very important and helpful in connecting the schedule data with the 4D models (Eastman et al., 2011).

- Transfer both 3D model and construction plan to 4D BIM tools

Because of the flaws and imperfection of the 2D/3D BIM tools non-auto method and 3D/BIM tools to 4D (built-in method), a lot of software and BIM tools arises to help to create a 4D model by connecting the schedule with the 3D model from different files or software. The new software or tools assisted the planners in many ways to improve the outcomes of the 4D model by giving them the advantage of modifying the 4D model to suit a particular task in that model. Mostly, the 4D model in these software or tools produce by importing the prepared schedule from specific planning or scheduling programs like Primavera or MS Project to the same file where the 3D model was imported to it after creating that 3D model in one of the BIM programs or even in CAD programs. After the importing and exporting, the planner will be able to connect the imported schedule tasks with the elements of that 3D model in order to produce a sufficient 4D model with time (Eastman et al., 2011). Figure 2.7 shows CAD and 4 Dimensions with BIM Tools.



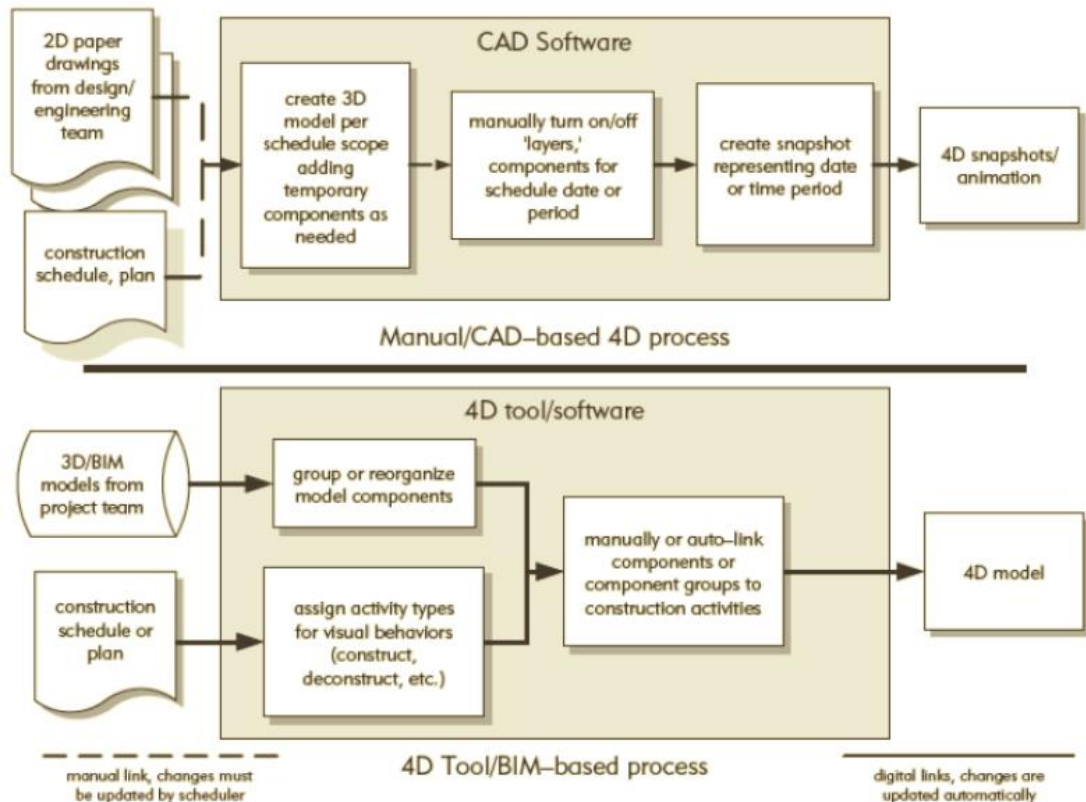


Figure 2.7: CAD and 4 Dimensions with BIM Tools (Eastman et al., 2011)

#### 2.2.4.2 4D BIM Planning Issues

The methodology and technique usually used to produce a schedule or plan differ in many ways from planning tool to other, however in creating 4D BIM models planners should pay attention to some issues (Eastman et al., 2011).

- Scope of created BIM model

This issue has a great significance in initial stages for the projects. The model can be created for a short time period to be used as an example for that (marketing purposes, design conflicts) or for a long time period as using the model for all the project stages. In this case the model will be more detailed depending on the owners' requirements, and the schedule for it should include more explained tasks that showed all the project stages from the start to the end with wider perspective (Eastman et al., 2011).

- Details of the BIM model

The time established to build a model, the critical tasks that have to be connected and the model dimensions or magnitude, all these parameters can influence the model details level. Architecture or engineer can give a high detailed level for retaining wall system including many elements to support the performance of physical objects. On the other hand, and from a contractor perspective this retaining wall system can be represented as one element only where the sequence of the retaining wall system here is more critical than the detailed level. A model with a large detail for composition, each progress in the project may be needed sometimes to help in the sequencing of the detailed elements. In situations like this planners can set various tasks to only one element. As an example, one retaining wall section can be divided as installation of steel bars, formwork and cast of concrete (Eastman et al., 2011).

- Organizing of the model elements

Mostly in using the 4D BIM tools planners can divide the elements of the model into several groups and they can re-organize them depending on the model plan. This advantage represents a great significance to the planners just as same as the architecture, engineer or the designer sorting the models is not always enough to link the elements of the model to the plan activities effectively. As an example, sorting the comparable elements like beams, columns and floors by the designers for absence of difficulty in updating the plan changes. Depending on the project sequences these elements will be ordered by the planners into regions of beams, columns and floors. Capability of re-organizing the elements have a high importance in improving the 4D model ductility and delicacy (Eastman et al., 2011).

- Non- permanent elements

To help the 4D BIM model to be more realistic and similar to the reality, activities and non-permanent elements should be added to it. For efficient simulation structures temporary tasks like excavations, scaffolding, tower cranes, and road diversions can be inserted in the 4D BIM model. The integral between any two of these temporary tasks in the 4D BIM model can be very helpful to the planner to assess the problems related to the safety or the construction stage (Eastman et al., 2011).

- Dividing the model elements

With the improve and growth of the 4D BIM models, the need for dividing an element which simulates physical objects into smaller parts may be helpful sometimes in order to present the suitable way to construct them. As an example, a floor has to divide into small parts to show the sequence of casting. Planners faces problems in this matter, when it comes to divide a certain elements like floors or beams, that the architecture, engineers or the designers defines it as a single element in the model. Nearly all of the 4D BIM tools can't deal with these issues, and the only solution available for the planners is by using the tool of 3D modeling (Eastman et al., 2011).

- Properties of Planning

In creating of 4D models the durations usually are set by planners as (early start and early finish) to make the plan more realistic and similar to the reality. And yet, in some cases the idea of using other durations like (later start and late finish) could be suitable to show the influence of other plans in the simulation procedures of the project (Eastman et al., 2011).

## **Chapter 3**

### **METHODOLOGY**

#### **3.1 Characterization of the Research Software**

Three software have been used in this chapter to help clarifying the research methodology: Autodesk Revit 2014, Microsoft Office Project 2013 and Autodesk Navisworks Manage 2014.

##### **3.1.1 Autodesk Revit 2014**

Autodesk Revit 2014 is considered as one of the best BIM tools when it comes to design, and it is published to the public by Autodesk Company. Revit helps to accomplish the methodology of the BIM and in this thesis it used to create the required BIM model. In this thesis a 3D BIM model has been generated with all the recommended features using the Revit 2014 before exporting the same model in Navisworks Manage 2014.

In spite of the fact that Autodesk Revit software can create a 4D BIM model by inserting the construction planning to the existing 3D model using the built-in feature provided by it, yet it's a difficult process when it comes to the arrangement of the stages and the sequence of the 4D BIM model. Revit allows to take snapshots for all the stages of the project. This can be based on the advantage given by this software to help the users to understand what's the adjustments required with time to enhance the efficiency of the project. But still with the presence of the Autodesk Navisworks

Manage as a 4D BIM tool, the use of Autodesk Revit is not recommended as a design tool to generate that 4D BIM model.

### **3.1.2 Microsoft Office Project 2013**

MS Project 2013 is published by Microsoft Company as a software specialize in the construction management fields to generate the construction planning. This software was involved in this study to create the suitable schedule for the railway bridge, which include description of the tasks, the duration related to them and the sequences for those tasks. This time plan was brought later to the Autodesk Navisworks Manage 2014 to help in transforming the 3D BIM model created in Autodesk Revit 2014 to 4D BIM model.

### **3.1.3 Autodesk Navisworks Manage 2014**

Autodesk Company supplied the market with three various versions of Autodesk Navisworks product, any of them has an uneven advantages from the others, and those versions are Autodesk Naviswork Manage, Autodesk Naviswork Freedom and Autodesk Navisworks Simulate. In this thesis Autodesk Navisworks Manage 2014 is involved in order to establish the methodology because it contains all the required advantages.

As a strong BIM tool, Autodesk Navisworks Manage 2014 with the feature of “Timeliner” provided in it gives an easier and clearer way to the users to generate a 4D model. Autodesk Navisworks used as a review, simulation and coordination BIM tool and in this software the modification applied to the model will have a zero effect in the main file or the model related to it.

With the feature of “Timeliner”, Autodesk Navisworks Manage 2014 helps in visualization of the model situation with time using the “Simulate” tab. Also Autodesk

Navisworks Manage 2014 has a dialogue to insert the outer information and refresh or delete the previous information.

## **3.2 Research Method**

Having done a review of literature in previous chapter, this chapter will focus on a case study of a railway bridge to explore the required understanding related to potentiality and difficulty connected to it using the BIM model tools.

### **3.2.1 Research Case Study**

In order to reach the aim of this research, 2D CAD drawings provided from Freyssinet Saudi Arabia Company for the Haramain High-Speed Rail Project, located at Jeddah - Airport East Interchange (HHR-AEI) has been obtained as a case study in this section. The high speed rail under Freyssinet SA scope comprises two links connecting the airport to Madinah at the North (link #1) and to Makkah at the South (link #2). Each one of the two links constitutes of two lines A & B for entrance to & exit from the airport. The total length of the links is 4,965m. The structure of the links is composed of segmental precast deck supported by piers with a height up to 16m. Deep & shallow foundations constitute the substructure. Long spans up to 110m are executed in balanced cantilever technique. All decks for road & railway bridges are in pre-stressed concrete, as per post-tension technique.

#### **3.2.1.1 Characterization and Achievement of the 3D BIM Model**

In this research the idea of not creating a hard and difficult BIM model was taken into consideration by the author because of the restricted time. Still, it is necessary to know that the need for the equipment's rises depending of the expansion of the created BIM model.

In the creating of the BIM model no particular standard or method for the design has been followed, the major concept has been to have a railway bridge with various elements to achieve the required analysis for it depending on the software features. The created 3D model in Autodesk Revit contains a railway bridge with 5 different foundations, 2 Abutments, 3 Piers, 16 Pads, 8 Precast Girders, Precast Slabs, Deck Slabs and Parapets. More elevations and sections views from Autodesk Revit 2014 are attached in Appendix A.

To generate a 4D BIM model using Autodesk Navisworks with a better simulation and in an easier and faster way, the need for defining the elements related to the 3D model created in Autodesk Revit has to be presented. Revit software contains the feature of “Project Parameters” in order to establish a new parameters under the name ‘Task ID’ for the all elements in the created project, which helps later in linking this elements with the specified tasks in the construction plan created in MS project to generate the required 4D BIM model in Navisworks Manage. As an example for that the Task ID for the first precast girder is “PG01” as seen in Figure 3.1.

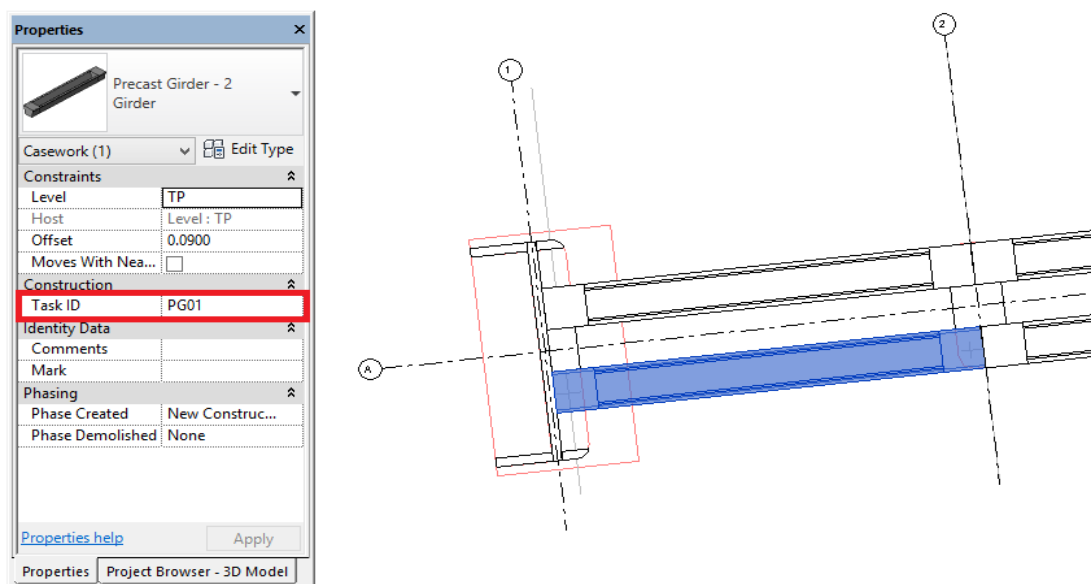


Figure 3.1: Task ID for First Precast Girder: ‘PG01’ (Revit 2014)

In this research a 3D model was created without any complications in the design as a RVT file format with size: 6496 KB. Figure 3.2 below shows the created 3D model in Autodesk Revit. Transferring this model to Autodesk Navisworks Manage is a second step and also generating the construction plan using MS Project 2013.

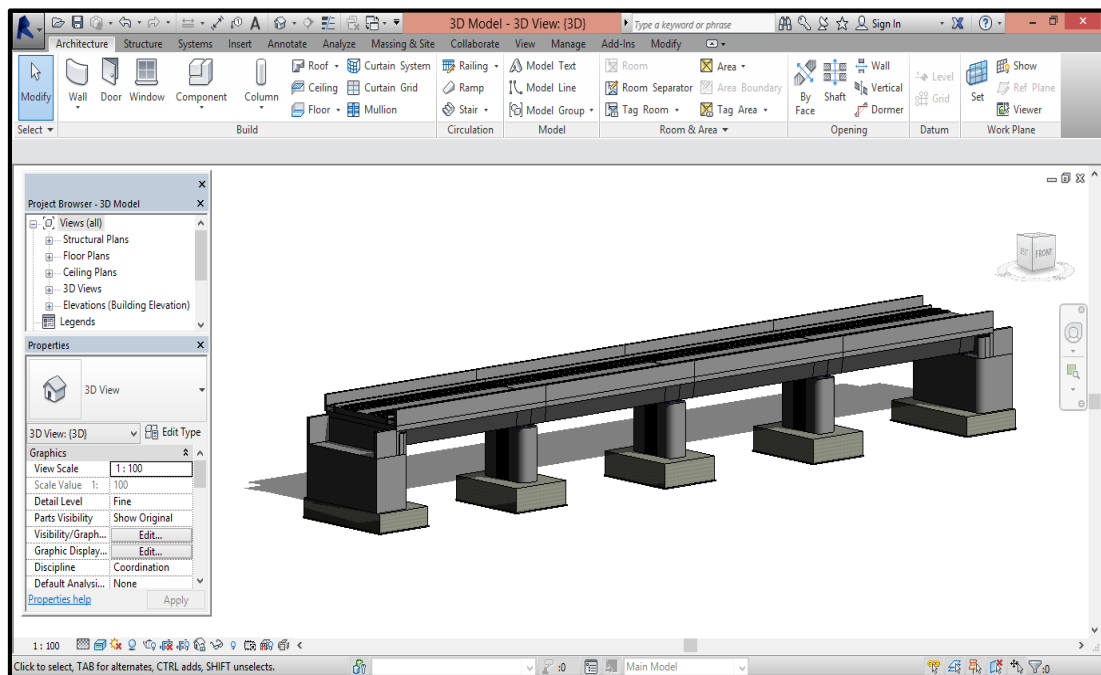


Figure 3.2: 3D Model Generated in Autodesk Revit 2014

### 3.2.1.2 Characterization and Achievement of the Construction Plan

A various theories can be adopted in order to develop a certain construction plan, and also similar results can be obtained from these theories but the only difference will be in the time factor between them. With the feature of “Synchronization” in Autodesk Navisworks Manage 2014, the capability of generating a construction plan using a suitable and specialized software like MS Project 2013 and transfer it next to Autodesk Navisworks can be done easily.



Project tasks and the sequences between them are determined in easy and clear way depending on the 3D created model. A suitable duration is also added to each task and the relations between them.

It is important to mention that if the construction plan will be generated in the Microsoft Project then the need of adding a new columns will be necessary. These new columns can be described as: (1) Task ID (the existing of this column depends on the use of the elements ID as in this research seen in Table 3.1; and (2) Task Type “Text 1” (this column shows whether a specific element in the project is construct, demolish or temporary as seen in Figure 3.3.

Table 3.1: Model Plan Tasks Names, ID`s and Durations

Task ID	Duration (days)	Task Name	Task ID	Duration (days)	Task Name
T01	2	Site Clearance	PA03	2	Pads at Pier-3
T02	6	Excavation Work	PG03	6	Precast Girders P2-P3
PC01	4	Plain Concrete	PA04	4	Pads at Abutment-2
F01	30	Foundations	PG04	30	Precast Girders P3 - A2
AB01	14	Abutment-1	PS02	14	Precast Slab P1-P2
PI02	9	Pier-2	PS01	9	Precast Slab A1-P1
PI01	9	Pier-1	DS02	9	Deck Slab and Parapets P1-P2
AB02	14	Abutment-2	DS01	14	Deck Slab and Parapets A1-P1
PA02	2	Pads at Pier-2	PS03	2	Precast Slab P2-P3
PI03	9	Pier-3	PS04	9	Precast Slab P3-A2
PA01	14	Pads at Abutment-1 & Pier-1	DS03	14	Deck Slab and Parapets P2-P3
PG02	15	Precast Girders P1-P2	DS04	15	Deck Slab and Parapets P3-A2
PG01	15	Precast Girders A1-P1	----	15	----

Some tasks in the construction plan may not indicate any element in the created BIM model but yet this task has a time factor and the need for it in the plan is inevitable.

Task Moc	Task ID	Task Name	Duration	Start	Finish	Actual Start	Actual Finish	Task Type
	PA02	Installation of Pads at Pier-2	2 days	Sat 10/3/15	Sun 10/4/15	NA	NA	Construct
	PI03	Provide and Cast R.C. for Pier-3	9 days	Sun 10/4/15	Mon 10/12/15	NA	NA	Construct
	PA01	Installation of Pads at Abutment-1 & Pier-1	4 days	Sun 10/4/15	Wed 10/7/15	NA	NA	Construct
	PG02	Installation of Precast Girders P1-P2	15 days	Mon 10/5/15	Mon 10/19/15	NA	NA	Construct
	PG01	Installation of Precast Girders A1-P1	15 days	Thu 10/8/15	Thu 10/22/15	NA	NA	Construct
	PA03	Installation of Pads at Pier-3	2 days	Mon 10/12/15	Wed 10/14/15	NA	NA	Construct
	PG03	Installation of Precast Girders P2-P3	15 days	Thu 10/15/15	Thu 10/29/15	NA	NA	Construct
	PA04	Installation of Pads at Abutment-2	2 days	Thu 10/15/15	Sat 10/17/15	NA	NA	Construct
	PG04	Installation of Precast Girders P3 - A2	15 days	Sun 10/18/15	Sun 11/1/15	NA	NA	Construct
	PS02	Installation of Precast Slab P1-P2	6 days	Mon 10/19/15	Sun 10/25/15	NA	NA	Construct
	PS01	Installation of Precast Slab A1-P1	6 days	Thu 10/22/15	Wed 10/28/15	NA	NA	Construct

Figure 3.3: Task Type and ID for Precast Girders P1-P2 in the Construction Plan (MS Project 2013)

Figure 3.4 below illustrates the created construction plan in Microsoft Project 2013. Now after finish from the plan, transferring it to Autodesk Navisworks will be next to generate the 4D model.

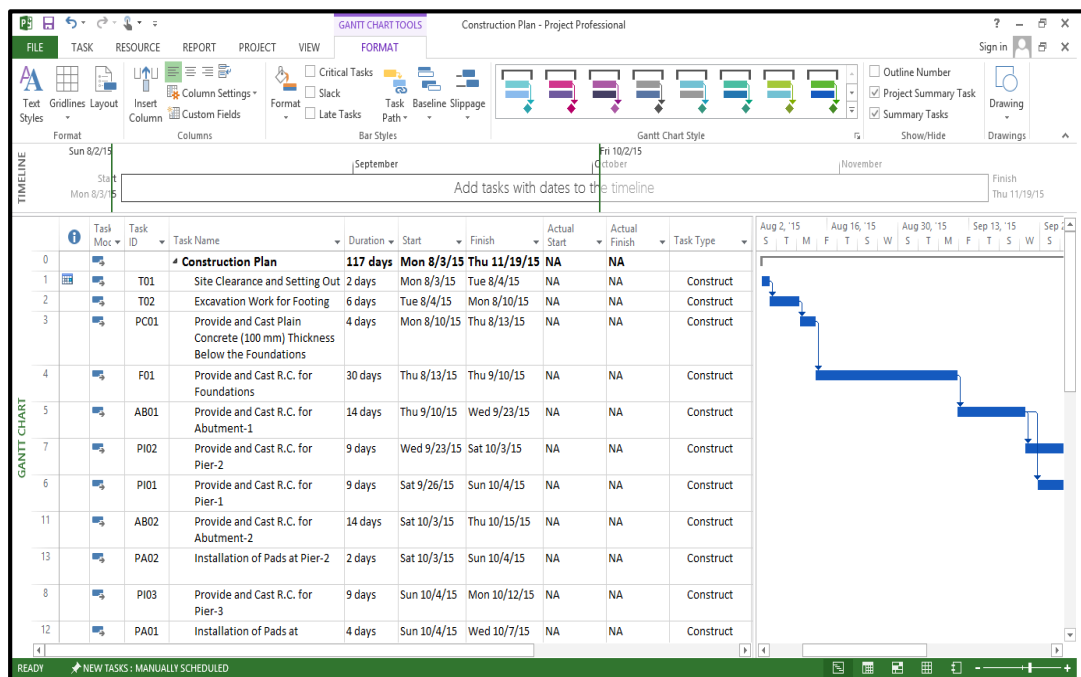


Figure 3.4: The Generated Construction Plan in Microsoft Project 2013

### 3.2.1.3 Generating the 4D BIM Model

When the processes of creating both of the 3D model and the construction planning finished, the need of transferring them into Autodesk Navisworks is required to generate the 4D BIM model. Because of the modifications that will appear later on in the 4D BIM model, the need to make a clear path during all that processes is very important.

#### 3.2.1.3.1 Transferring the 3D model from Revit to Navisworks Manage

The idea of gaining knowledge is very necessary when it comes to the various Autodesk Navisworks file formats. These formats can be divided into three as following:

- **Navisworks Cache File Format (NWC):** the Cache format is the main format of the Autodesk Navisworks. The attached source file (Revit file) will be connected to the Cache file. Creating a NWF file format can done from the NWC Cache file format. And it has the advantage of reducing the created model from the main size until 90%.
- **Navisworks Document File Format (NWD):** It is considered as a very helpful format to be used between the project staff. It gives “snapshots” to the present view and also this file format is counted as a full file which can be opened using any of the Autodesk Navisworks product.
- **Navisworks File Format (NWF):** In this file format, no elements from the model are saved in it. It depends on the elements from the source files. This type of file is generally recommended to use. It is linked with the source file (Revit file). To establish a NWF file format a clear way to connect with the source file must be provided. This file format also allow to establish a NWD Document file format as seen in Figure 3.5.



Figure 3.5: Various Files Format for Autodesk Navisworks (Autodesk, 2014)

To transfer a BIM model generated in Autodesk Revit file to Autodesk Navisworks two ways can be used to accomplish that: (1) by importing the BIM model from Revit when the Navisworks start to work or (2) by exporting that model from Autodesk Revit to Navisworks Cache file format. Yet, both ways will give the same thing because when the users import a Revit file and save it into Autodesk Navisworks, a new Cache file format will be generated as the second way. As mentioned before, this NWC file format will allow to create a NWF file format or even a NWD document file format.

By selecting the suitable Autodesk Navisworks file format to the created BIM model, this model will be ready to the next step. Figure 3.6 below shows the BIM model in Autodesk Navisworks. For the aim of this research a Navisworks file format (NWF) was used. The construction planning will be inserted as the next stage to bring the time factor.

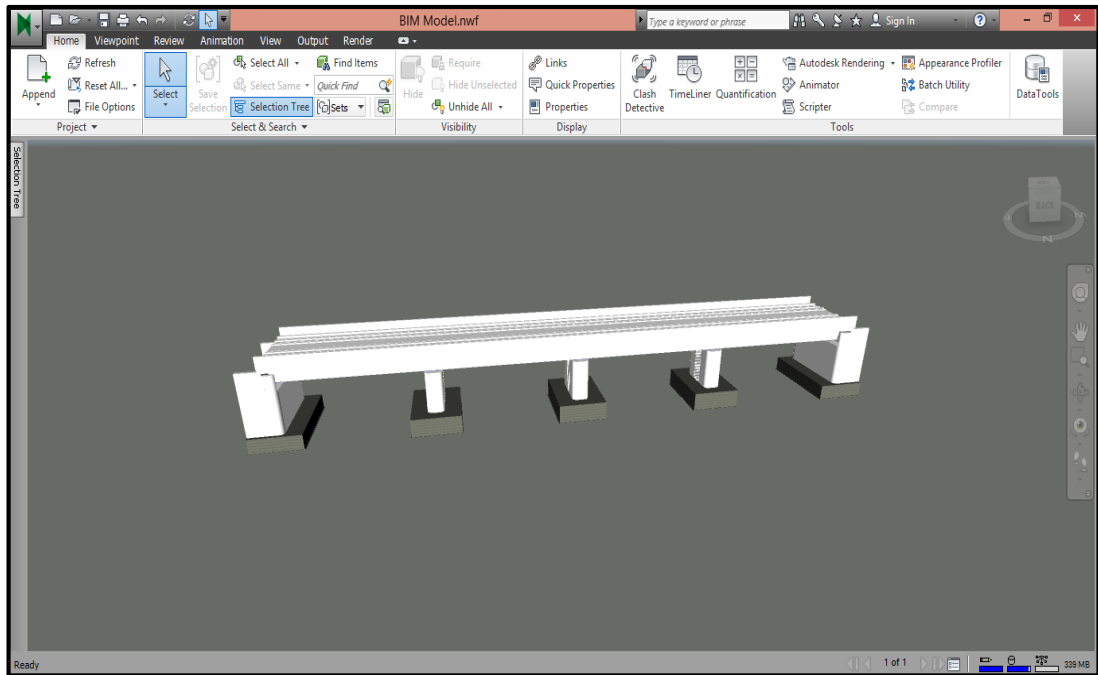


Figure 3.6: 3D Model Transferred to Autodesk Navisworks Manage 2014

### 3.2.1.3.2 Creating Elements Sets for the Model

After transferring the created 3D model from Autodesk Revit to Navisworks Manage and before running the simulation for the model elements, one of the most necessary process has to be done is that “Sets” feature contained in Navisworks Manage has to be used in order to generate a new sets for the model elements depending on the method that selected to be performed in the created construction plan. As an example, particular model elements are connected to a specific task in the created plan.

At this situation, same like in the construction plan, all the model elements are sorted depending on the construction type. For example, elements that describe installation of pads between two piers is defined in single separate task. These process of “selection sets” is considered as a fundamental process to represent the connecting between the elements and tasks which done after importing the construction plan. Also other features contained in Navisworks Manage which is “Selection Tree”, this feature comes very handle in generating the sets automatically depending on the classify of

the model elements, which will give a faster and efficient way of selecting any part in the model. In addition, if greater than one model is imported, the sets for each one of them will be defined in the “Selection Tree”.

From the moment of generating the sets, each time a set is chosen, all the model elements contained in that set will appear automatically in the model with different color as seen in Figure 3.7 and after that it can easily connect them to the created construction plan. More than that, the feature of “Hide Unselected” helps to show the selected element in the model alone and hide all the other elements as seen in Figure 3.8 which can be very helpful in monitoring and studying the selected elements and also having a better visualization for it.

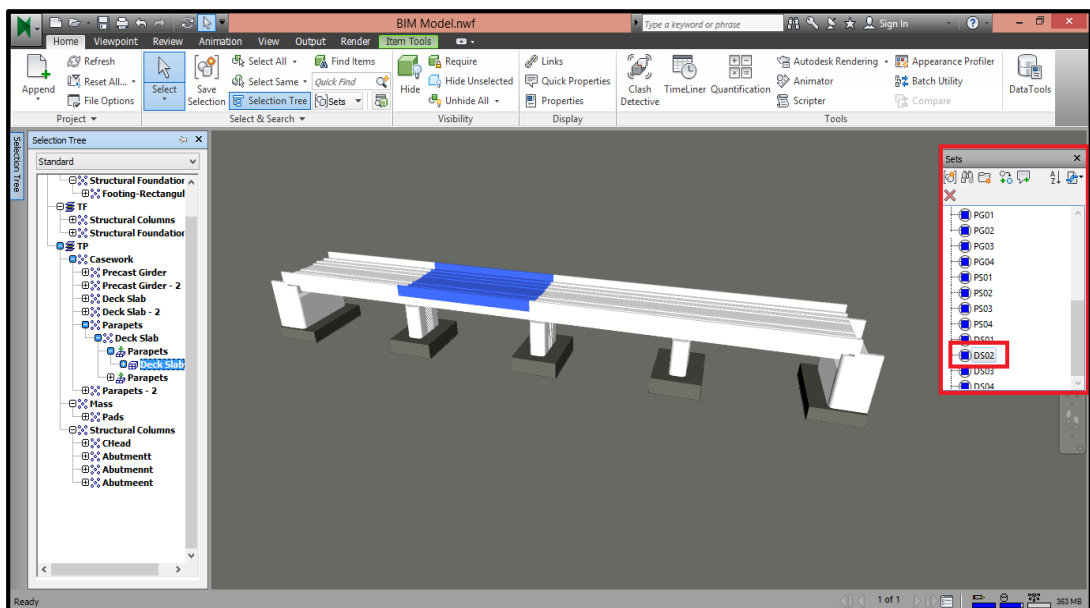


Figure 3.7: Elements Sets: ‘DS02’ Colored in Blue (Autodesk Navisworks Manage 2014)

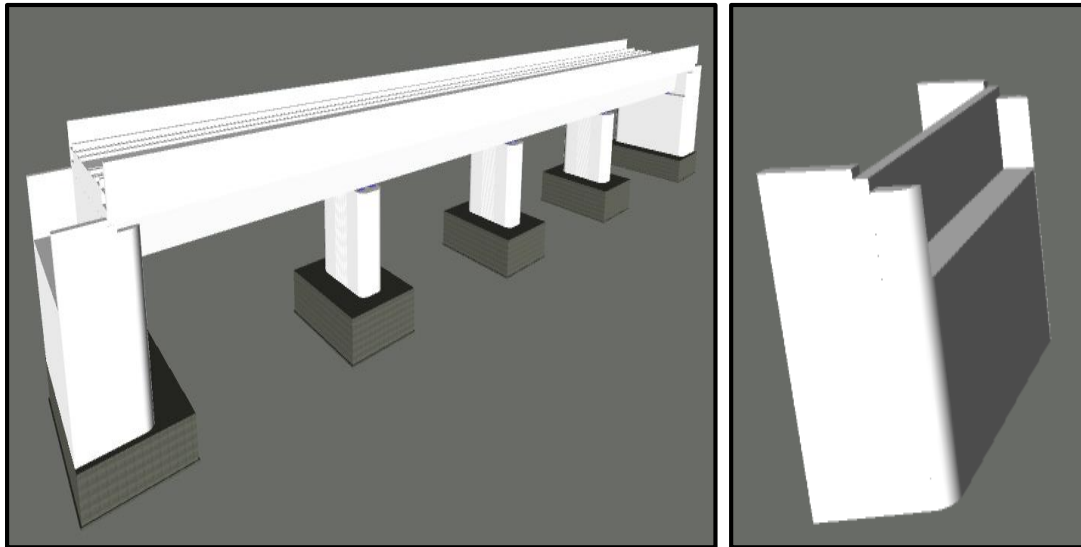


Figure 3.8: 'Hide Unselected' Shows the Abutment-1 Alone After Hiding the Rest of the Elements (Autodesk Navisworks Manage 2014)

Also Autodesk Navisworks Manage has extra feature which is 'Find Items'. This feature helps to find the specific item in the model depending on the names or properties which consider very important when it comes to the complicated models.

### **3.2.1.3.3 Transferring the Construction Planning from Microsoft Project to Navisworks Manage**

The construction plan can be generated in Navisworks Manage as same as different planning software using the feature of "Built-in" but as mentioned before this has been neglected. Because of that, the need to transfer the created construction plan from another planning software (Microsoft Project) and import it in Navisworks is to be illustrated under this section.

Using the feature of "TimeLiner" in Navisworks and "Data Sources" from it gives the chance to generate new links with different plan types as (Microsoft Project 2007-2013) contained in this types. The construction plan must have a second mapping (adding tasks, columns) in Microsoft Project and that done when the plan import to Navisworks, this will help the data to the Navisworks "TimeLiner". "Field Sector"

window is the specialist in that, this window appears every time a plan is imported. And in this research, for that window a certain areas has been selected (Figure 3.9). Because the “Field Sector” as mentioned before consider as a part of “Data Sources”, each time a modification happened in the connected construction plan the need of “Synchronize” or “Rebuild Task Hierarchy” features to update the plan in Navisworks became necessary. “Synchronize” feature helps to update the activities information from the main file, and “Rebuild Task Hierarchy” feature helps to import all the activities connected with the main file.

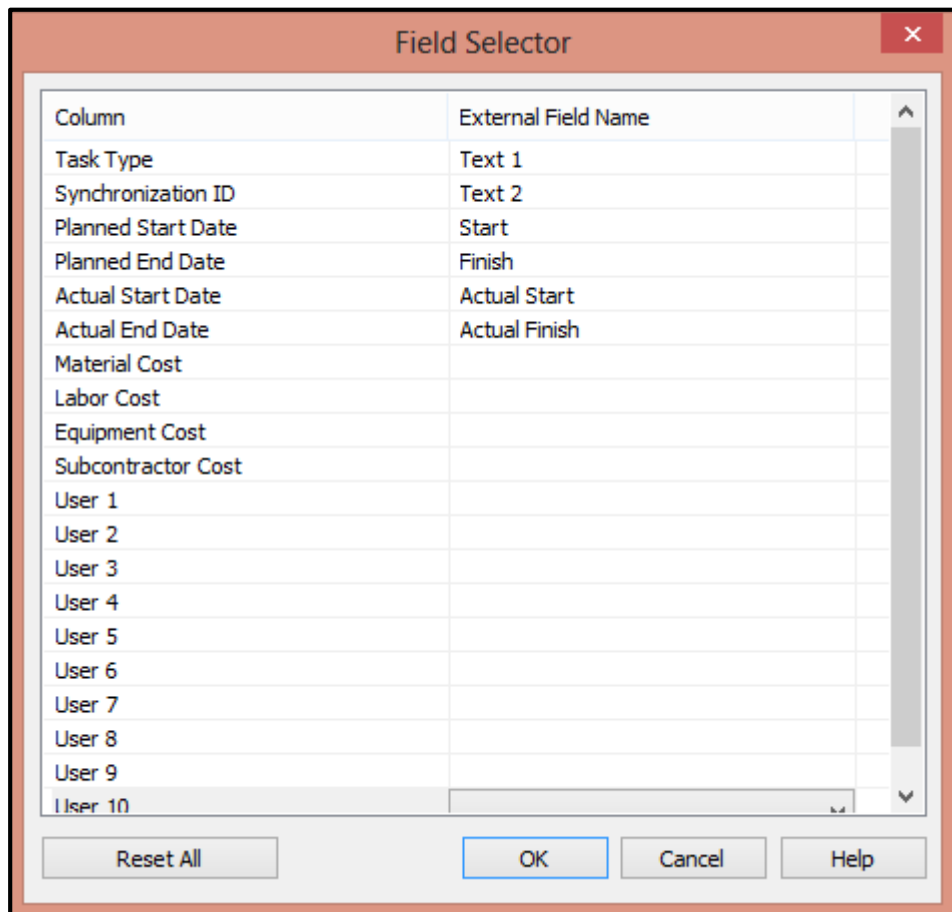


Figure 3.9: ‘Field Selector’ Feature Shows the Selected Areas (Autodesk Navisworks Manage 2014)

It’s important to mention that the feature of “Data Sources” allow to import several plans into Navisworks and attached to one model.



#### **3.2.1.3.4 Connecting the Model Elements with the Plan Activities**

This is considered as one of the advantages for the BIM 4D simulation, the capability of the Navisworks Manage to connect the elements related to the model with the construction plan tasks. This connection can be completed separately for each element with the related task in a non-automatic way, yet it will not be efficient in complex projects like railway bridges which will take a lot of time to finish it with the possibility of errors. Because of that, the need for auto-connecting gives an efficient and better result.

Because of that, “Auto-Attach Using Rules” contains in “TimeLiner” feature in Navisworks serve that purpose. The option “Map TimeLiner tasks to selection sets with the same name” is considered as the best option in this situation because the sets were generated with that aim, still it can do it by using other options like “Map TimeLiner tasks to layers with the same name”. The “Attached” column will show the set connected to the specific activity (Figure 3.10).

Additional options under “Auto-Attach Using Rules” consider effectively, in the rule templates the option “Attach items to tasks by Category/Property” is considered helpful in using the model elements properties like “Task ID”. By using this option (Figure 3.11) there is no need for generating the sets because of the Auto-connecting. In this situation the “Attached” column will not show the connections as “Selection Sets” but as “Explicit Selection”.

Whatever was the connecting procedure, from the moment of connecting an element with an activity all the data related to the activity in the “TimeLiner” appears in the properties of that element. Also the option of “Attached Items” in “Find Items” feature

gives the capability to observe if the model elements are connected efficiently with tasks.

Active	Name	Status	Planned Start	Planned End	Actual Start	Actual End	Task Type	Attached
<input checked="" type="checkbox"/>	<b>4D Palnning (Root)</b>		8/3/2015	11/19/2015	N/A	N/A		
<input checked="" type="checkbox"/>	Site Clearance and Setting Out		8/3/2015	8/4/2015	N/A	N/A	Construct	
<input checked="" type="checkbox"/>	Excavation Work for Footing		8/4/2015	8/10/2015	N/A	N/A	Construct	
<input checked="" type="checkbox"/>	Provide and Cast Plain Concrete (100 mm) Thickness Below the Foundations		8/10/2015	8/13/2015	N/A	N/A	Construct	Sets->PC01
<input checked="" type="checkbox"/>	Provide and Cast R.C. for Foundations		8/13/2015	9/10/2015	N/A	N/A	Construct	Sets->F01
<input checked="" type="checkbox"/>	Provide and Cast R.C. for Abutment-1		9/10/2015	9/23/2015	N/A	N/A	Construct	Sets->AB01
<input checked="" type="checkbox"/>	Provide and Cast R.C. for Pier-1		9/26/2015	10/4/2015	N/A	N/A	Construct	Sets->PI01
<input checked="" type="checkbox"/>	Provide and Cast R.C. for Pier-2		9/23/2015	10/3/2015	N/A	N/A	Construct	Sets->PI02
<input checked="" type="checkbox"/>	Provide and Cast R.C. for Pier-3		10/4/2015	10/12/2015	N/A	N/A	Construct	Sets->PI03
<input checked="" type="checkbox"/>	Installation of Precast Girders P2-P3		10/15/2015	10/29/2015	N/A	N/A	Construct	Sets->PG03
<input checked="" type="checkbox"/>	Installation of Precast Girders P3 - A2		10/18/2015	11/1/2015	N/A	N/A	Construct	Sets->PG04
<input checked="" type="checkbox"/>	Provide and Cast R.C. for Abutment-2		10/3/2015	10/15/2015	N/A	N/A	Construct	Sets->AB02
<input checked="" type="checkbox"/>	Installation of Pads at Abutment-1 & Pier-1		10/4/2015	10/7/2015	N/A	N/A	Construct	Sets->PA01
<input checked="" type="checkbox"/>	Installation of Pads at Pier-2		10/3/2015	10/4/2015	N/A	N/A	Construct	Sets->PA02
<input checked="" type="checkbox"/>	Installation of Pads at Pier-3		10/12/2015	10/14/2015	N/A	N/A	Construct	Sets->PA03
<input checked="" type="checkbox"/>	Installation of Pads at Abutment-2		10/15/2015	10/17/2015	N/A	N/A	Construct	Sets->PA04
<input checked="" type="checkbox"/>	Installation of Precast Girders A1-P1		10/8/2015	10/22/2015	N/A	N/A	Construct	Sets->PG01
<input checked="" type="checkbox"/>	Installation of Precast Girders P1-P2		10/5/2015	10/19/2015	N/A	N/A	Construct	Sets->PG02
<input checked="" type="checkbox"/>	Installation of Precast Slab A1-P1		10/22/2015	10/28/2015	N/A	N/A	Construct	Sets->PS01
<input checked="" type="checkbox"/>	Installation of Precast Slab P1-P2		10/19/2015	10/25/2015	N/A	N/A	Construct	Sets->PS02
<input checked="" type="checkbox"/>	Installation of Precast Slab P2-P3		10/29/2015	11/4/2015	N/A	N/A	Construct	Sets->PS03
<input checked="" type="checkbox"/>	Installation of Precast Slab P3-A2		11/1/2015	11/7/2015	N/A	N/A	Construct	Sets->PS04
<input checked="" type="checkbox"/>	Provide and Cast R.C. for Deck Slab and Parapets A1-P1		10/31/2015	11/10/2015	N/A	N/A	Construct	Sets->DS01
<input checked="" type="checkbox"/>	Provide and Cast R.C. for Deck Slab and Parapets P1-P2		10/26/2015	11/7/2015	N/A	N/A	Construct	Sets->DS02
<input checked="" type="checkbox"/>	Provide and Cast R.C. for Deck Slab and Parapets P2-P3		11/5/2015	11/17/2015	N/A	N/A	Construct	Sets->DS03
<input checked="" type="checkbox"/>	Provide and Cast R.C. for Deck Slab and Parapets P3-A2		11/9/2015	11/19/2015	N/A	N/A	Construct	Sets->DS04

Figure 3.10: 'Auto-Attach Using Rules' by 'Selection Sets with the Same Names' (Autodesk Navisworks Manage 2014)

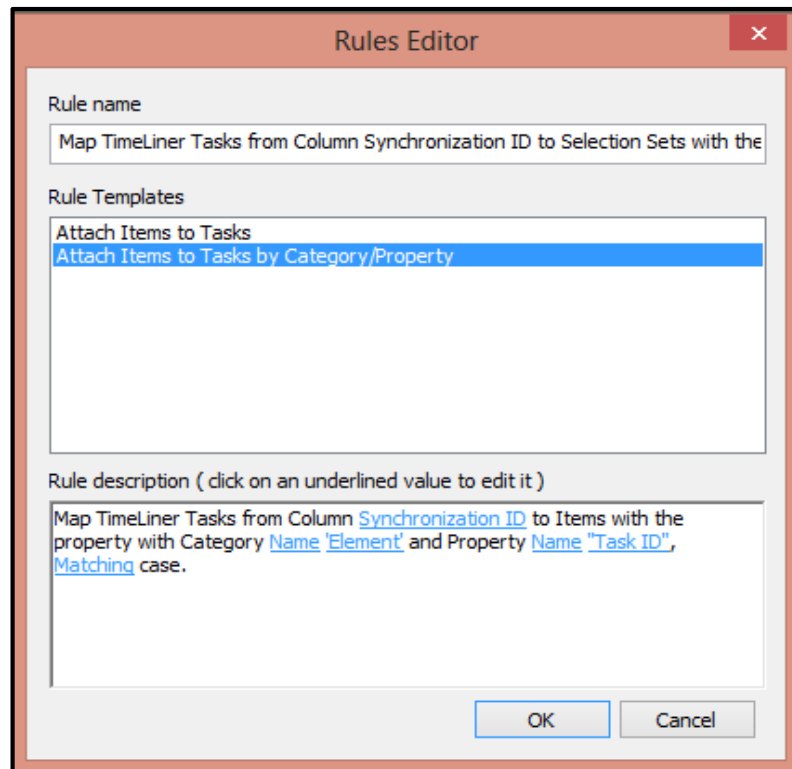


Figure 3.11: 'Attach Items to Tasks by Category/Property' (Autodesk Navisworks Manage 2014)

### 3.2.1.3.5 Research Method for bringing the Construction Plan into Navisworks Manage

Several methods can be used to import the created construction plan from any planning software to Navisworks Manage and that is dependent on how the plan was generated.

This research adopted the Task ID method (Section 3.2.1 & 3.2.2). Firstly external parameter was shared into the project parameters and the ID for each of the model elements was identified in Revit before imported into Navisworks. Secondly, in Microsoft Project additional column was inserted in the construction plan to identify the ID for each activity under the same ID name from Revit also before importing the plan into Navisworks. As it seems that this method may take extra time but this is only

in the first procedure, because when the work on Navisworks start everything will be Auto-connected (Figure 3.12).

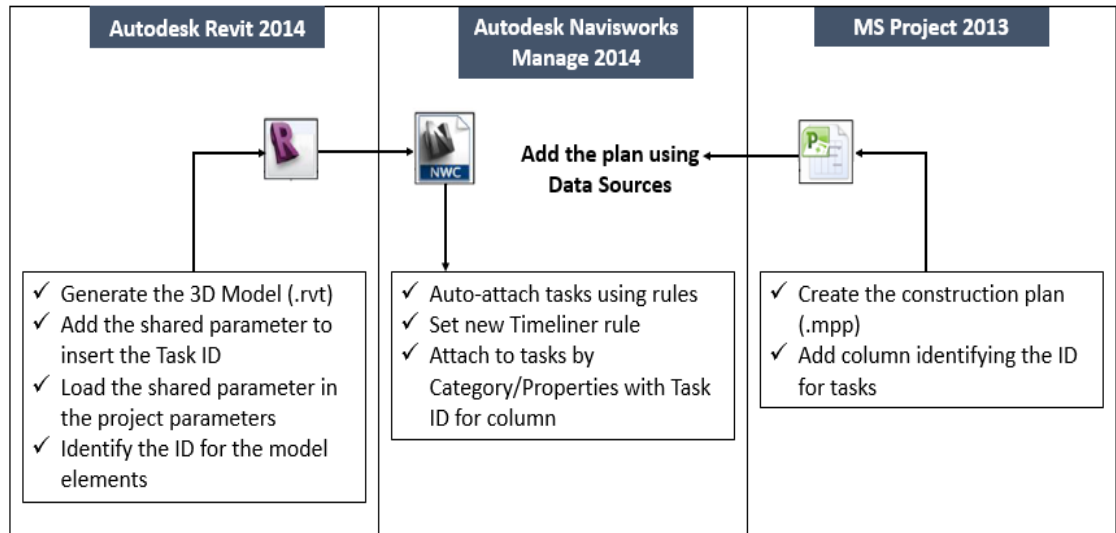


Figure 3.12: The Adopted Task ID Method

After creating the 4D BIM model with suitable method, the need for analysing and running the model will be next.

## **Chapter 4**

# **RESULTS AND DISCUSSION**

### **4.1 Introduction**

This chapter will focus on the analysis of the 4D BIM model from the start to the end, in order to monitor and check the model elements conditions with the time factor. Evaluation for the 4D BIM tool has been done depending on the outcomes of the results. Additional to comparison between Navisworks Manage and the traditional construction planning methods.

### **4.2 Analysis and Running the 4D BIM Model**

#### **4.2.1 Model Visualization**

As mentioned in the previous chapters, the model visualization is considered as the main advantage when it comes to the 4D modeling. Autodesk Navisworks Manage is one of the effective BIM tools that specialize in the model visualization.

Navisworks Manage provides the advantage of the construction plan visualization for any of the model elements from different views, that is helping to check the elements conditions under the specified durations. Any of the elements that finished upon the related duration will be appear with different color than the others as seen in Figure 4.1. It's important to mention that there is only a slight different between both of the construction plan visualization and the model simulation.

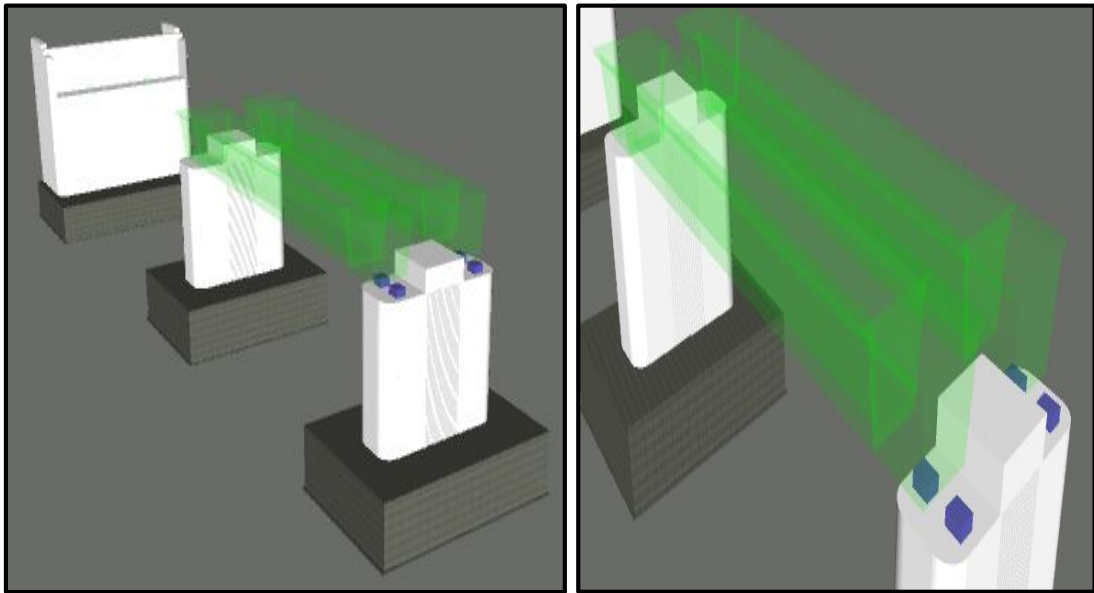


Figure 4.1: Installing of the Precast Girders between P1 and P2 from different views (Autodesk Navisworks Manage 2014)

#### 4.2.2 Model Simulation

The simulation process for the created railway bridge model was run easily in Navisworks. This software represent a coordinator 4D BIM tool (Section 4.2.1), helps to detect the design future errors using a typical simulation to the reality.

The simulation in this software can be run in different ways, like starting the simulation from the first day of work to last day or the opposite. It can also be paused or modified to a certain date in the construction plan. Observation for a specific element in the model also can be done by selecting start and end dates to the simulation process depending on the duration for that element. Above on that, Navisworks allow to monitor the simulation process from several views and gives the capability of zooming during that process. Figure 4.2 illustrates the planned work for the railway bridge by ‘Tuesday 20/10/2015’ (Yellow Square).

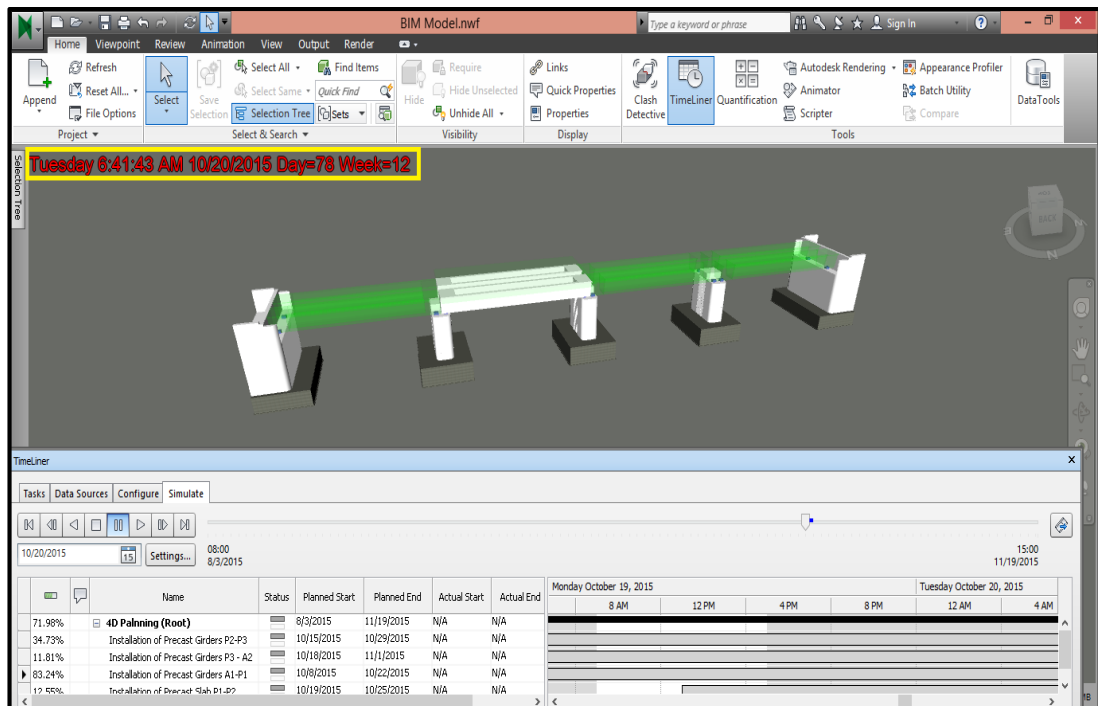


Figure 4.2: Simulating Process for Precast Girders (P1-P2) Installation  
Date: Tuesday 20/10/2015 (Autodesk Navisworks Manage 2014)

From the figure above it can be noticed, that the first precast girders (P1-P2) will be installed at the date marked in the yellow square.

It's important to mention that the quality of the figures related to any of the software in this research was brought as a snapshots which consider the best way available to bring a software view into document papers.

The simulation of the 4D BIM model was recorded in a video attached to this research and some of the railway bridge sequences was illustrated in (Appendix B).

### 4.3 Research Outcomes based on the Analysis

Depending on the outcomes of the research analysis, the evaluation for Navisworks Manage 2014 has been done in this chapter.

### **4.3.1 Evaluation of the 4D BIM Tool**

As in this research a non-complicated BIM model related to the railway bridge was used in order to create the 4D BIM model. Still this non-complicated model was able to help in generating a BIM simulation for the project, project plan visualization, Re-evaluation for the construction plan and to discover the future errors for that plan. But still Navisworks Manage 2014 as a 4D BIM tool is fluctuated when it comes to the levels of the satisfaction between the above tasks. Table 4.1 below illustrates the different of the satisfaction levels among several tasks in Navisworks related to this software as a BIM tool. The method followed in this thesis contained two other softwares (Autodesk Revit 2014, and Microsoft Project 2013), yet the evaluation in this chapter will focus only on the Navisworks Manage as a satisfied 4D BIM tool.

Navisworks Manage 2014 satisfies with a full marks four of the tenth tasks mentioned in “Table 4.1” below, which can be listed as: (1) Project plan visualization; (2) Model simulation; (3) Connection and collaboration for the project contributors; and (4) Building project related decision.



Table 4.1: Several satisfaction levels of construction management tasks served in Autodesk Navisworks Manage 2014

Evaluation for a different BIM tasks in Navisworks Manage 2014			
Is Autodesk Navisworks 2014 satisfy the different BIM demands tasks?	Satisfy	Not Satisfy	Remarks
Project Plan Visualization	Satisfy		Capability of visualizing the plan created in Microsoft Project. This task is totally satisfied.
Model Simulation	Satisfy		The feature "Simulate" in this software gives the capability to simulate the models elements with the plan activities. This task is totally satisfied.
Connection and collaboration for the project contributors	Satisfy		The first and second tasks makes the connection easier between the work members (limpidity). This task is totally satisfied.
Building project related decision	Satisfy		It continuously support the process of making decision in different examples through an optimized visualization. This task is totally satisfied.
Re-evaluation for the construction plan	Satisfy		The features "Synchronization" and "Switchback" in this software can work as useful features for this task.
Activities time status	Satisfy		The features "As-planned" and "As-built" shows with colors technique.
Discover future errors	Satisfy		The feature "Time-based clashing" help in enhance the discovering of the model future errors.
Exploitation of the project actual location	Satisfy		General visualization for the actual location workflow can be done with the temporary imported project equipment's.
Allocation the project resources		Not Satisfy	No features in Navisworks, only what created in the plan obtained from Microsoft project.
Health and Safety		Not Satisfy	Not supported by this software.

As mentioned above, four of these tasks has been totally satisfied when the other six tasks had a lower level of satisfaction, but still from (Table 4.1) four of these six tasks were categorized below 'Satisfy' column.

The two additional tasks which were classified below ‘Not Satisfy’ column meaning that both of them were not supported in Autodesk Navisworks Manage 2014. This software can't depend on when it comes to allocation of the project resources especially if it was put against the Microsoft Project. Additional to that, using Navisworks as a BIM tool to serve the project health and safety maybe will support the users with better visualizing for the project but also it will give a zero outcome for the health and safety. Which maybe it can be as a new section to be develop in the future by the BIM.

#### 4.4 Comparing the 4D BIM with the Traditional Planning Methods

After the evaluation for the Navisworks Manage as a 4D BIM tool, the need for a comparison between the 4D modeling method and the traditional planning methods (Critical Path Method) has to be covered (Table 4.2). The aim is to understand the advantages of the 4D BIM modeling, and to prove the present of it as a superior construction planning method than the existed methods.

Table 4.2: Comparison between the 4D BIM Modeling Method and the Critical Path Method

4D BIM Modeling Method	Critical Path Method
Create connections between the project stakeholders	No connections between the project stakeholders
Present the project activities as a 4D model	Present the project activities as arrows and nodes
Visualizing the model from different views	Two dimension view
Re-planning can done in the initial stages by the advantage of detecting the future errors	Re-planning cannot done before the actual site work start
Typical simulation to the reality	No simulation
Work successfully with the complicated project	Not recommended in the complicated projects
Easy to control the schedules of the persons involved in the project	cannot form and control the schedules of the persons involved in the project

## Chapter 5

### CONCLUSION AND RECOMMENDATION

#### 4.1 Conclusion

This section of the study focuses on the conclusion obtained from the previous chapters. Containing the positive and negative points for Navisworks Manage 2014, as a 4D BIM tool used to generate a railway bridge project. The upcoming challenges have been also covered, in order to improve the 4D BIM tool to work effectively in the infrastructure sector. The outcomes of the research recommendations, and the recommendations for future studies are presented.

##### 4.1.1 Navisworks Manage Positive Points as a 4D BIM Tool

This software was designed to serve as a 4D BIM tool, and it's still considered as one of the best tools in the 4D BIM field. That can be returned to the positive points included in it as listed below:

- Because of the advantages of the model simulation and the project plan visualization this software can work as a very useful BIM tool for the construction plan process with an excellent connection and collaboration between the project contributors. Above on that, ongoing visualization for the plan can be done without forgotten the elasticity in creating and re-evaluating that plan. That's why several of the BIM demands tasks was satisfied by Navisworks.

- Autodesk Revit and Autodesk Navisworks contain clear steps help to export and import the model in an easy way among the two software. Also the features “Synchronization” and “Switchback” are very useful with the progress of the project work.
- The availability of ways to create a new methods in this software (Task ID method) is considered as an advantage compared with the traditional methods.
- Navisworks Manage has the capability of combing all the 4 Dimensions BIM features that required from it as a representing tool.

#### **4.1.2 Navisworks Manage Negative Points as a 4D BIM Tool**

As this software have a garneted place with the top 4D BIM tools and with the mentioned positive points above, still Navisworks did not satisfy all the 4D BIM requirements with a list of negative points as below:

- The important negative point in Navisworks Manage is that this software was created as a coordinator software without giving the users the capability to make any changes on the imported model that created in another software, which will not help that much to represent the overall concept of the 4D modeling.
- Using a similar perspective as in the first mentioned point, the capability of updating the construction plan imported in Navisworks Manage cannot be done inside this software. In order to do that, the only way available is by updating it in the original planning software that was created in it (MS Project) then using the feature "Synchronize" adopted in Navisworks "Timeliner" to replace the updated plan over the existing one.

- For the models with complicated elements, it's better to split those elements to smaller ones to enhance the model simulation. Yet, this cannot be done inside Navisworks since it is designed as coordinator tool.

#### **4.1.3 Upcoming Challenges**

- Protecting the positive points and find a better solutions to reduce the negative points that mentioned above.
- The development of the 4D BIM concept should focus on making all the procedures required in order to generate a 4D BIM model to be done in one individual software. In this case, the opportunity of making a four dimensions model with a completed construction plan will increase, since the links required to connect the plan activities with the model elements can create easily.
- Also for the activities time status and beside the existing color technique additional help will be valuable. For example, two simulation processes for both of the "As-planned" and 'As-built" will give the creators a clear idea about the workflow.
- After working and covering all the software used in this study, the author likes in his upcoming practical life to work more with another BIM tools related to the concept of the four dimensions, especially when it comes to the railway bridges.

#### **4.2 Recommendation**

Depending on the outcomes of this study, the helpful recommendations that obtained is listed below:

- As the method used in this research is the only way available to generate a 4D model with a BIM tool is to use two extra software which has been done and satisfied the goals of this study by monitoring and controlling the

construction process with time. Yet, the need for a single independent application to create the 4D BIM model should be the priority.

- Infrastructure projects in general should have some attentions from the BIM since it was focused mostly on the building and the highway bridge; by improving the tools related to the BIM to work in an efficient way in order to generating a railway bridge as example.
- Until now, the 4D BIM tools has fulfilled most of the construction management's requirements. But the rest of that requirements should cover as soon as possible in order to reach the owners satisfaction with that 4D BIM concept.
- Saudi Arabia as country with that size and potentials should change the way of designing, presenting and executing the construction projects and switch from the traditional ways to adopt the concept of the BIM.
- The platform of learning the BIM dimensions should not be restricted only on the practical life. It should be started as a main course in our undergraduate studies with practical parts which will allow to enhance the mentality of the future engineers, especially in the Africa and Gulf Area.

#### **4.4 Recommendation for Future Studies**

After conducting the studies it is prominent that 4D modeling is beneficial for the planning process in the infrastructure sector. A good topic to study further can be how much beneficial is 4D modeling for the railway bridge planning, that is, if it is highly effective or not? And if it is highly effective then why it is not yet widely accepted within the infrastructure sectors? These subjects, however, were not covered in the initial purposes of the thesis and hence, be suggested as topics of research for future studies.

In future research, the validity and reliability of the study should be increased by conducting practical interviews or surveys with construction project stakeholders. Furthermore, applying 4D modeling on runtime projects of a railway bridge firm could be of great help for collecting actual data and information and determining the effectiveness of 4D modeling. Not only such experience will reinforce the statement of findings and discussion, it will develop a broader and holistic perception of 4D planning in infrastructure projects as well.

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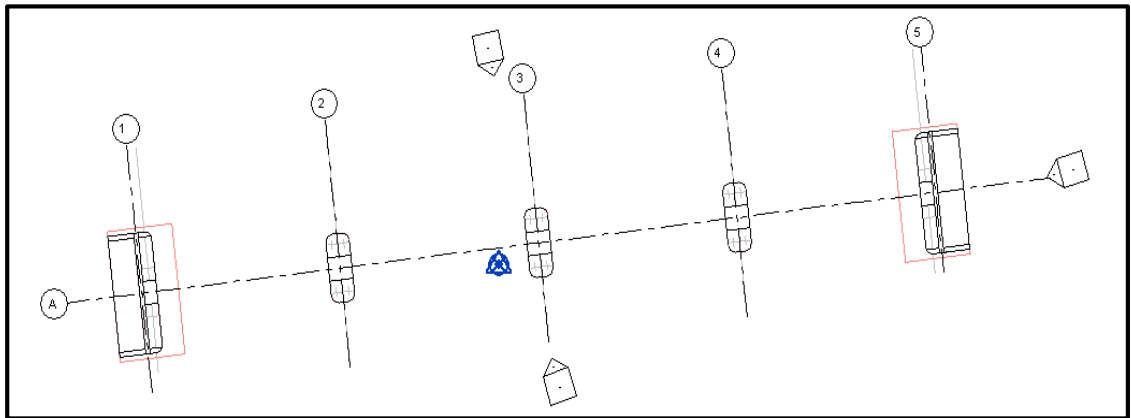
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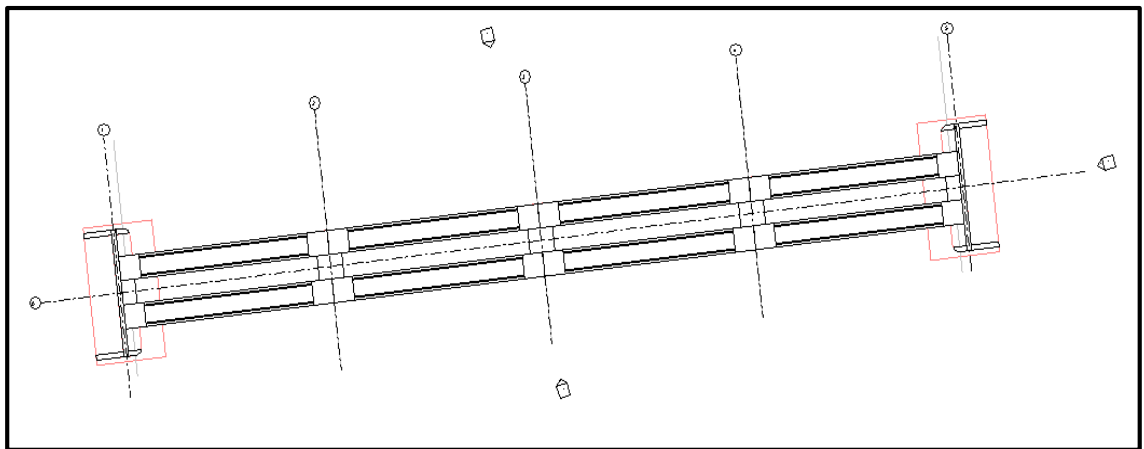
## **APPENDICES**

## Appendix A: Railway Bridge as 3D BIM Model

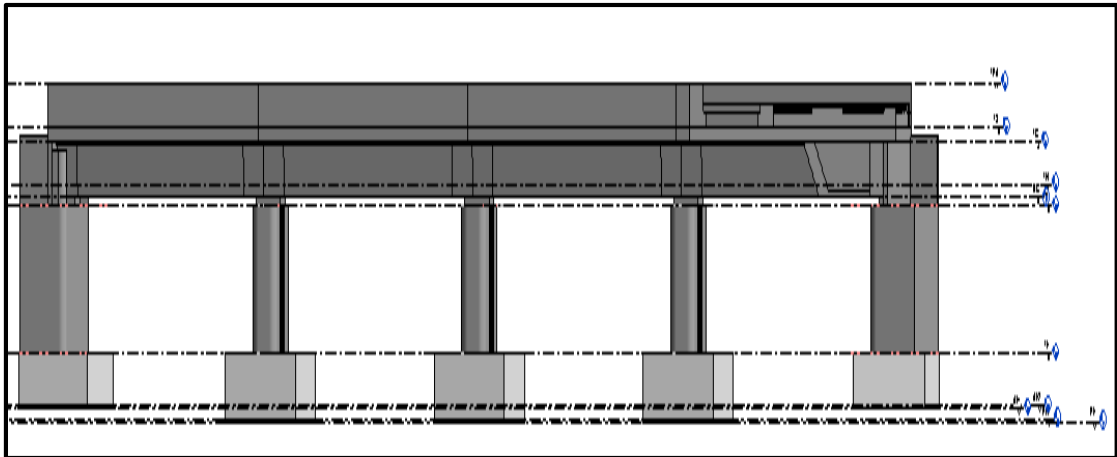
The below views taken as a snapshots related to the created three dimensions model of the railway bridge using the 3D BIM tool Autodesk Revit 2014.



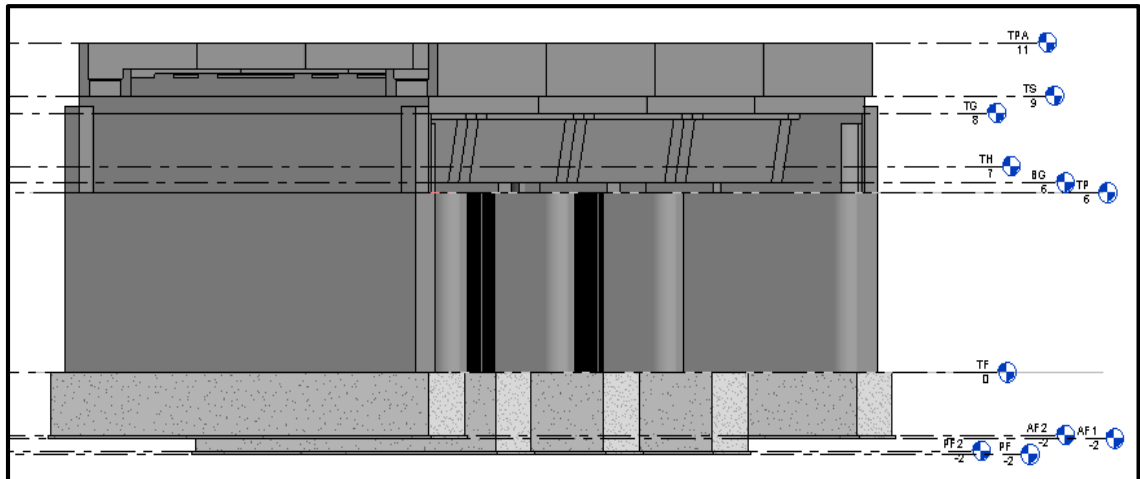
Top view for the railway bridge site plan



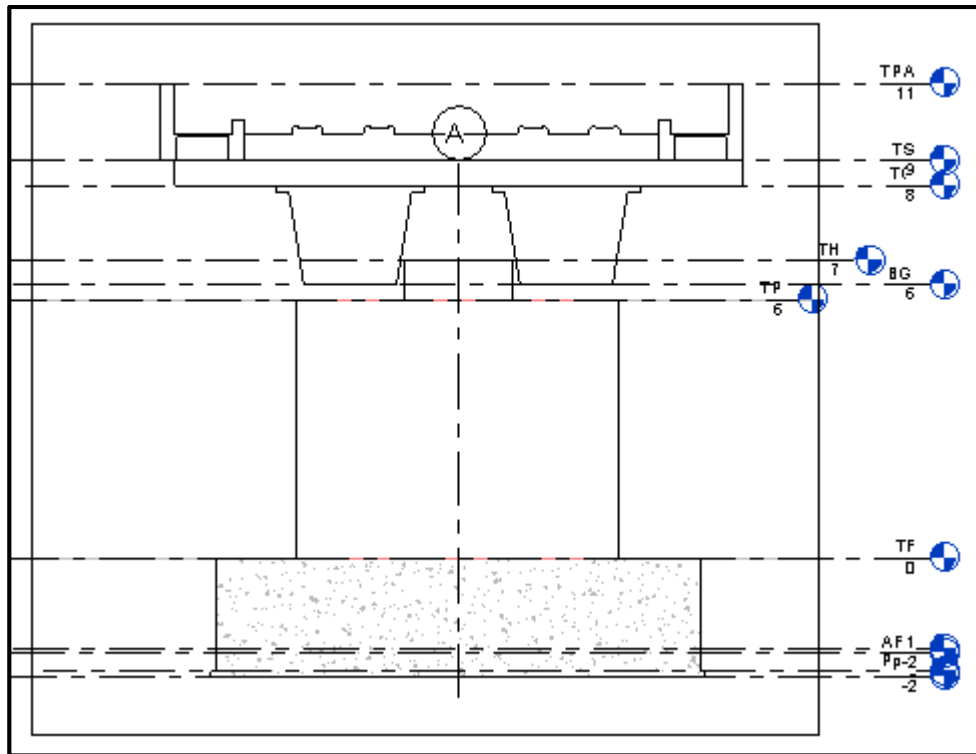
Top view for the precast girders top levels plan



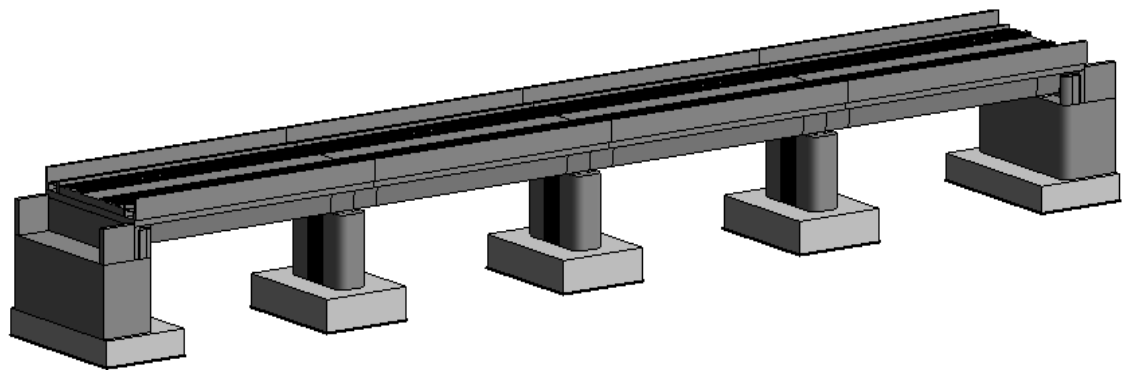
3D model south elevation for the railway bridge



3D model east elevation for the railway bridge



Cross section for the railway model bridge



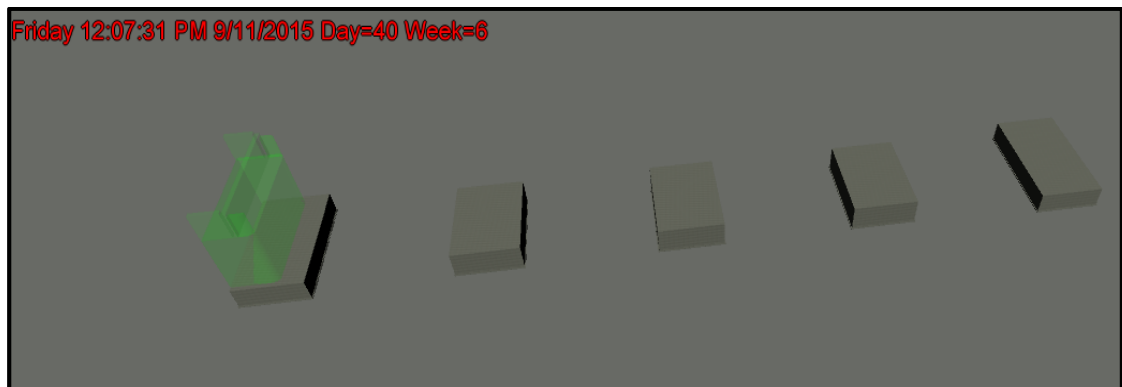
Generated 3D BIM model for the railway bridge in Revit 2014

## Appendix B: Railway Bridge Sequence Simulation

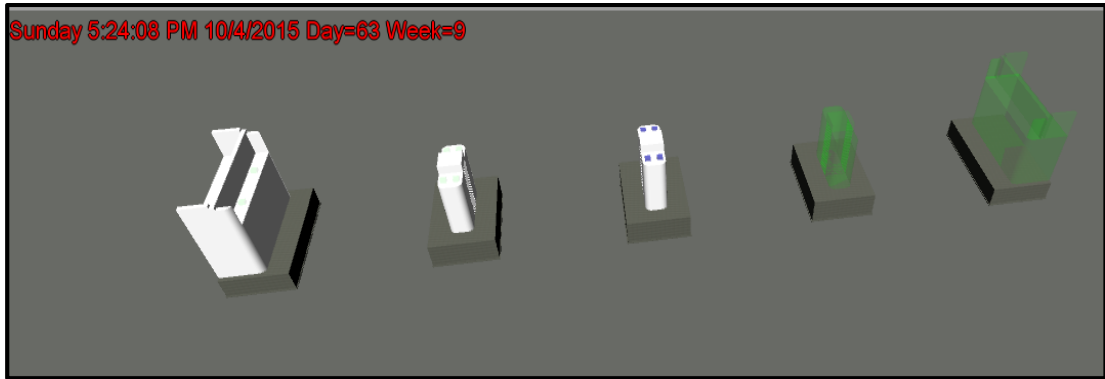
The below photos shows the construction sequence of the railway bridge using the concept of 4D with Autodesk Navisworks Manage 2014 as a BIM tool:



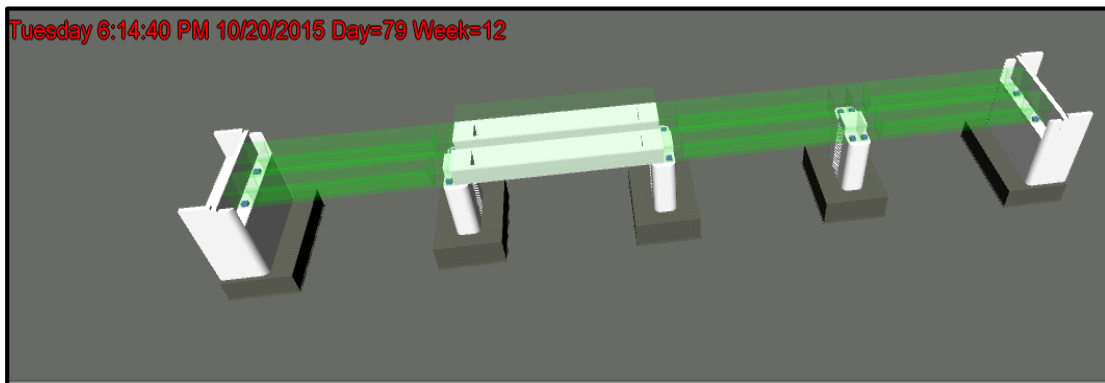
Underground work for foundations: Thursday, 13 August 2015



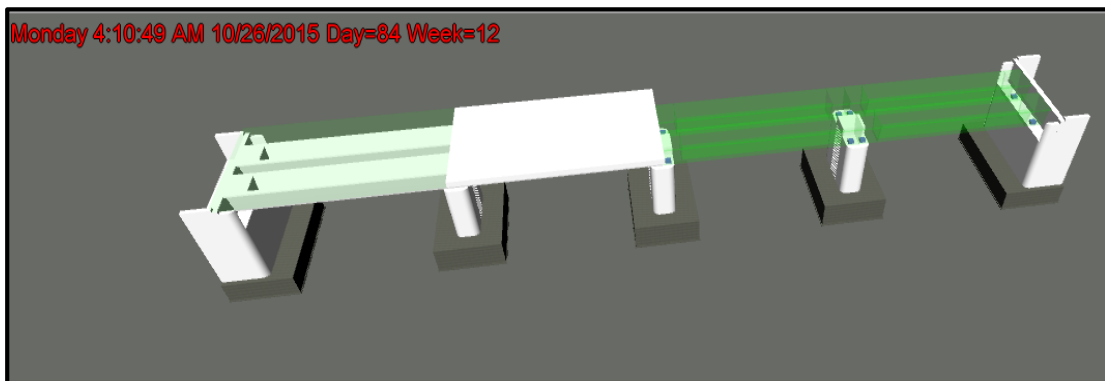
Erection for the bridge Abutments and Piers: Friday, 11 September 2015



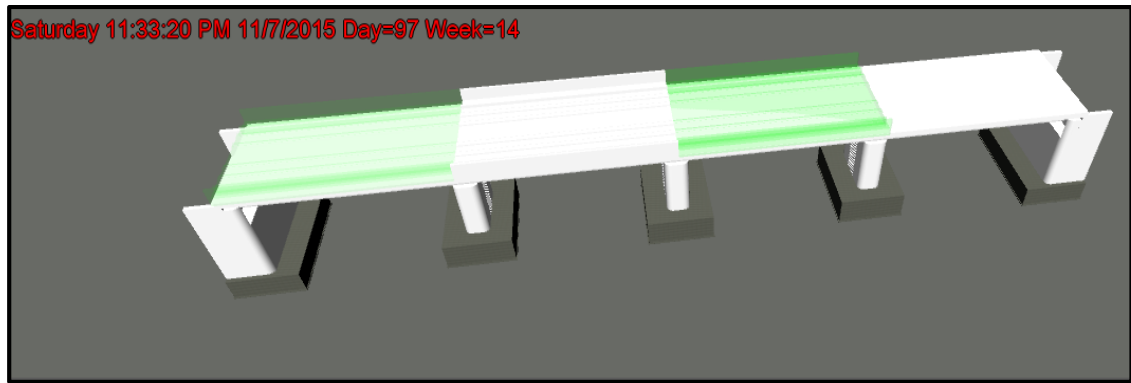
Installation of the first bearing pad: Sunday, 04 October 2015



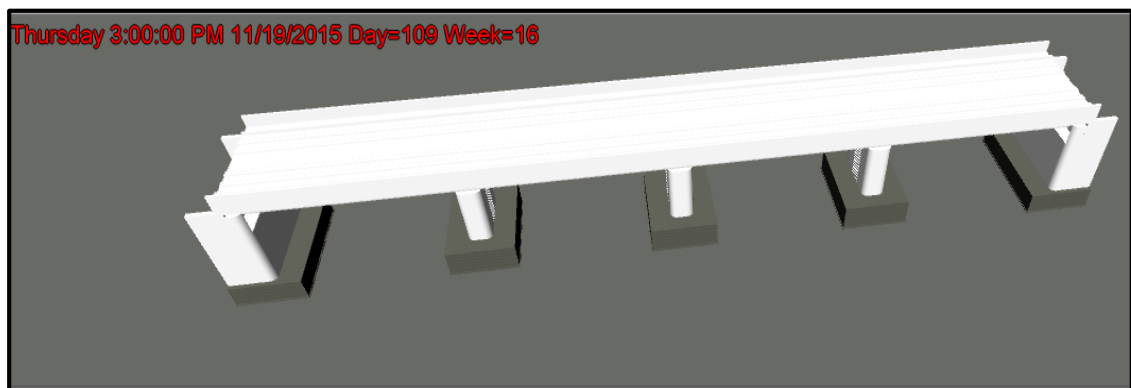
Installation of the precast girders: Tuesday, 20 October 2015



Installation of the first precast slabs: Monday, 26 October 2015



Installation of the first deck slab and parapets: Saturday, 07 November 2015



End of the construction work for the railway bridge: Thursday, 19 November 2015

- CD will be attach to this research contains a video (.AVI) for the 4D BIM simulation sequence.