Building Information Modeling (BIM): Site-Building Interoperability Methods

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By

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Abstract

Nowadays, many companies in the Architecture/Engineering/Construction (AEC) industry are using Building Information Modeling (BIM) in achieving a faster, sustainable and more economic project. Among the new developed concepts and BIM applications, two of the concepts most frequently used with the support of BIM technology in the planning, organization and scheduling of projects are 4D and 5D in which a 3D model is tied to its time execution (4D) at any point in time and its corresponding cost (5D). However, most of these applications concentrate on modeling the building but it does not include a corresponding modeling of the site in which the building is located. To date, there are few studies and systematic implementation of the site and the building integrated into one BIM model. This site-building integrated model can also be conceptualized as "6D BIM" model.

The benefit of integrating the site and building together into one model is that the building is no longer treated in isolation of its surround site but incorporates extremely helpful short-term and long-term information for the owner, designer, and builder regarding site topography, landscaping, access roads, ground conditions and the location of site utilities.

Major existing research and technology issues that are preventing this site-building integration deal with functionality and interoperability of the BIM software, different orientation and coordination of building model and site model.

The objectives of this thesis are to explore current organizational and technological issues preventing this integration, to investigate a feasible method to create a site-linked BIM model, and to discuss the benefits and limitations of bringing

BIM concept to the site conditions.

The research has been conducted by an extensive review on the literature related to the topic of interest published primarily by AEC. A review on current applications of Geographic Information Systems (GIS) has also been included because of the wider context provided by this technology to the specific topic of this research. Related BIM software developed by three different vendors —has been discussed and compared to determine the level of feasibility and operational features of technological support necessary to implement the site-linked BIM model. A case study based on the design and construction of the WPI Recreational & Sports Center, currently under construction, was developed to explore and understand the details that are involved in creating a new site model and to link it with the existing 3D building model. What has been learned from the analysis of this case study is presented, discussed and analyzed in terms of benefits and limitations.

Recommendations for future extensions from both the research aspect and the technology support aspect finally presented. These include the creation of 3D BIM Campus Map, which is one site model with several building models placed on it to facilitate future planning of new building and/or maintenance and operation of the current buildings and campus infrastructure.

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1. Introduction

It is attributed that the term "BIM" was first coined in the late 1970s by Charles M. Eastman and the concept of Building Information Modeling has been first used in the mid-1980s (Eastman, 1975). Later definitions of this term include the one by Phil Bernstein (Kiviniemi, 2010) and many others who have followed. However, the theory of this concept has not been really applied in the Architecture/Engineering/Construction (AEC) area until the recent 10 years (Yessios, 2004).

In today's AEC area, "BIM" is no longer a strange word. Actually, it has become more and more popular in different design and construction related areas. Some people may still have confusions of what BIM really is by asking, is it just software? Or it is a new CAD technology? But more and more people start to realize BIM is a process of generating and managing building data during the building's life cycle (Lee, *et al*., 2006). It is a revolutionary approach to design construction and maintenance operations that promise to speed construction, improve collaboration among different parties, control the cost of the change order, and reduce possible inefficiencies so that the overall productivity can be enhanced (BIM at MSU, 2008).

Nowadays, more and more owners and Architecture/Engineering (AE) firms have introduced the concept of BIM using 3D modeling to support both the preconstruction and the construction process. Many new terms, concepts and BIM applications have been developed such as 4D, 5D, 6D and 7D. The "D" in the term of 3D BIM means "dimension" and it has many different purposes for the construction industry. 3-Dimensional means the height, length and width. 4D BIM is 3D plus the factor of time, which in the context of BIM used in construction planning implies, the project

schedule; 5D BIM is 4D plus cost estimation; 6D BIM is 5D plus site, which means a 3D building model linked with a 3D site model, and the integrated model should also carry all the project schedule and estimation information; and even the concept of 7D BIM has been brought up, which is BIM for life-cycle facility management (Review of BIM, 2011).

Through a wider and wider application of BIM, certain benefits of using this computer-aided technology have been found out and confirmed. The key benefit is its accurate geometrical representation of the parts of building in an integrated data environment allowing for a more coordinated production of documents in 2D and 3D, it provides a better visualization of the design which would help the owner to confirm if the final building would meet his/her expectations; meanwhile, BIM as an single integrated information resource, would make the communication and coordination among project participants much easier. Some other benefits of BIM are faster and more effective processes, better design, controlled whole-life costs and environmental data, better production quality, automated assembly, better customer service and lifecycle data for facility management (Azhar, 2011).

As the benefits of using BIM being realized by people in the AEC industry, the concepts of 3D, 4D and 5D BIM are more and more frequently used with the support of BIM technology in the planning, organization and scheduling of projects. However, most of the discussions associated with BIM are concentrating on modeling the building solely, not much has been found regarding BIM for the corresponding site in which the building is located. To date, there are few studies and systematic implementation of integrating the site and building into one single model. The benefits of using BIM concept to define site conditions are mentioned in some research paper, however, none of them has provided an in-depth discussion focusing

on, what are the strength and weakness of doing so, what are the detailed feasible methods of using BIM concept in defining site conditions and technology support that we can use in the real world, not to mention the topic of linking site and building model together.

The 6D BIM model, comparing to the 3D model, would carry the building information as well as the necessary site data. This would require the integration of Geographic Information System (GIS) and BIM. The GIS in this thesis would be discussed from three different levels, from the whole world GIS to the mini GIS, which is a site model with several building models on it, and then the scope would be narrowed down to the topic of single site linked with single building. With the integration of GIS, all the items in the site model would carry the exact location and elevation information (X, Y, Z) as they are in the real construction world. And these geographic data could coordinate with the orientation and elevation of the building model, which would realize the final integration of the building and the site.

Thus, the objectives of this thesis are the following two: one is to explore current organizational and technological issues preventing this integration and to investigate a feasible method to create a site-linked BIM model; the other is to discuss the benefits and limitations of bringing BIM concept to the site conditions.

The literature review for this paper contains both the broad topic of BIM and GIS, as well as the specific topic of site-building integrated BIM model. Major resources are books and journals published by American Society of Civil Engineers (ASCE), paper and standards from Open Geospatial Consortium (OGC), also the white papers, news reports from the BIM software vendors' websites such as Autodesk®,Inc., Bentley Systems and Graphisoft SE   since the technology is changing rapidly in the construction area.

In addition, to explore and confirm what are the feasible methods of creating a site-integrated BIM model, software products developed by different companies have been considered, four procedures have been compared, the advantages and disadvantages of each method were discussed. The WPI Sports and Recreation Center, which is currently under construction, was selected as a case study to testify one of the method — Revit Architecture and AutoCAD Civil 3D. In the case study, the functionalities of different BIM software were listed and compared; Specific issues regarding both the ground and underground site conditions were defined, and corresponding solutions of using BIM were provided.

Benefits and limitations of the site-building integrated model were discussed as a conclusion of what BIM has brought us on site. Future work were proposed from three aspects, one is to continue research of the site model itself; the second is from the aspect of applications, explore the method of using other software products to create a site-linked BIM model; last but not the least, is to expend the research of single site and building to the digital campus maps, which would be a site with several buildings sitting on it.

2. Background

Building Information Modeling (BIM), as one of the recent developments in the architecture, engineering, and construction (AEC) industry，is no longer a strange word. The model built by this technology, known as Building Information Model, could be used for planning, design, construction and facility operation (Azhar, *et al.* 2008). This chapter presents a review of many publications on the broad topic of BIM, as well as the specific topic of site-linked BIM. This review includes among others books and journals published by American Society of Civil Engineers (ASCE), paper and standards from Open Geospatial Consortium (OGC), which is a non-profit international voluntary consensus standards organization that is leading the development of standards for geospatial and location based services. The knowledge base in this field is changing rapidly and there is new material that is constantly published in the form of white papers, news reports from the BIM software vendors' websites such as Autodesk®,Inc., Bentley Systems and Graphisoft SE.

This literature review is aimed to build a clear and systemic understanding about the rapid evolution of BIM is in the AEC and Facility Management (FM) industries, as well as how BIM has been evolving and applied from a global perspective. More specifically, through the reading of these literatures it has been possible to learn how much work has been done on this topic, what is still missing, what difficulties people in these areas have met, what the major obstacles are and what specific problems that need to be solved in the future.

2.1 Building Information Modeling

In today's design and construction industries, 3D building modeling has become more and more widely used as an efficient process that is changing the way in which the AEC industry delivers projects. Architects use it as a better design tool, which provides a 3D visualization of their proposed design idea to their clients; engineers also benefit themselves from the use of 3D and BIM to better coordinate their designs and to better integrate the analytical part of their professional services detecting clashes between systems and estimating energy efficiencies.

Most of the discussions associated with BIM have focused on the preconstruction phase. Some of the hot research issues are related to "the ownership of the model", "the trends, benefits, risks and challenges of BIM for AEC industry" and "how 3D and 4D BIM model would benefit the AEC area" (Azhar, 2011). However, to this date not much attention has been given to the topic of site linked model which is starting to emerge. Searching the key word "BIM" or "building information modeling" through Google, reports more than 11,000,000 hits. However, if we narrow our search by the words "BIM site", "3D site model", or "site linked model", one would get only one tenth of the original results or less.

In this area, there are some discussions concerning BIM for Civil Engineering. The topic ranges from "exploring the different uses of BIM model for Civil Engineering" to "how could site, road and highways exploit the advantages of a BIM-enabled workflow, and etc. (Strongitharm & Philbrick, 2009). Other discussion focus on the meaning and benefits of using the BIM concept to define site conditions. For example, the contractor's guide to BIM published by Associated General contractors (AGC) concluded the advantages of bringing BIM to the site conditions are: *"identifying*

collisions to reduce errors and corrections in the field, having more reliable expectation of field conditions studying which would enable a safe, simulated environment;; being able to incorporate more prefabricated components and assemblies (Sullivan, 2007)." Furthermore, in some related case studies like the design and construction of Emory Psychology Building, which is located in Atlanta, BIM has been considered very efficient in defining underground coordination. In this case, a site model was created, the early collision detection and interference checking was performed by using Revit Architecture, utility model was created using a 2D drawing and it shows the structure in relation to the underground utilities which revealed several conflicts (Ospina-Alvarado & Gerhart,2008).

The publications referred above are related to integration of BIM and site work, however, not much was found discussing the strength and weaknesses of doing so, what are the operational and organizational feasible methods of using BIM concept in defining site conditions and technology support that can be practically implemented. Therefore, this research focuses on addressing the following issues.

1. Identify and explore a feasible method of using BIM concept in defining construction site condition.
2. Propose and test a method to integrate site-linked building model vs. architectural/structural building model.
3. Discuss organizational aspects for project implementation of site-linked building model, benefits and limitations for different users.

2.2   GIS & the Construction Site

When comes to the topic of site and building model, another basic concept becomes very important, that is "Geographic Information System (GIS)". The U.S. Geological

Survey (USGS) defines GIS *"a computer system capable of assembling, storing, manipulating, and displaying geographically referenced information (that is data identified according to their locations)"* (Dempsey, 2011). In the simplest terms, GIS is an advanced information technology that enables people to make and use spatial information in all aspects of human life. Thus, when we narrow down the research scope of GIS to the construction area, the site related GIS would provide a potential solution for some spatial related problems such as the complex construction site layout, integration of site information (Bansal, 2007). In this section, the discussion would start from the general overview of GIS, and then the scope would be narrowed down to the construction area, which would lead to the specific problem of integrating BIM and GIS for modeling a site and a single building.

Figure 1: Three levels of GIS

The concept of GIS would be divided into three different levels. One is the whole world GIS, which is the general GIS from a global perspective. Then narrow down the scope to the construction field, it comes to the mini GIS, which is a site with several buildings on it. And then it would lead to the final level, a site with a single building sitting on it, which would be the focus of this research.

➢ Whole World GIS: From a global perspective, more than 80% of information in our daily production and life is related to geographic location and space (Liu, 2011). Thus, GIS can be widely applied in various fields of people's lives. The world's major challenges, pollution, uprising population, natural disease, all of these can be affected by geographic factor. In the real life business, GIS can also be used in many ways, for example, it can be used to find out the most suitable place to plant strawberry, or to find the best route for an ambulance in a traffic congested city.

➢ MINI GIS: There is a significant amount of research has been done related to GIS, topics are very broad from the guide to this technology (Antenucci, 1991) to the basic data structure for GIS (Parmenter, 2007), from the principles of GIS modeling (Porter, 2005) to GIS for utilities and facility management (Rich & Davis, 2010). Studies of GIS have extended into many different fields during all these years. In the design and construction field, we need to integrate GIS with BIM, so that the sphere of research interests could be narrowed down to the topic of site related GIS for building and managing infrastructure.

A college campus is usually a practical application for GIS that is defined by a small geographic region. A digital campus map could be created by modeling the whole campus site and all the building on site. In the year 2000, Saint Mary's University of Minnesota (SMU) has created an campus model using ArcView 3.2 software, the GIS included building, trees, streams athletic fields, gas lines, fire hydrants, sidewalks, parking lots and so on. This GIS map allowed the visitors to view the campus and find campus locations easily, and could also be used by SMU for building projects and campus expansion as it proposed (Meier, 2000). However, what was missing in this case is the necessary building information,

and although everything is digital on this map, none of them are really three-dimensional, which is of the main objectives of this study. Integrate GIS with a BIM model, allows for a richer utilization and coordination of site and building information by users. The method proposed to accomplish this integration consists of creating a site model that contains all necessary geographic information and then link it with an existing building model.

➢ Single Building & Site: This research further narrows down and focusing on GIS and BIM for only one site linked with one building. In several research papers, a host of hot issues discussed on BIM and GIS, such as whether these two technologies can coexist. The integration of the 3D BIM into the geospatial context seems to be crucial to address the challenges of sustainable management and development of the built environment (Hijazi, *et al.* 2010). Another topic related to the Geographic Information System, is related to the geographic coordination between the site plan and its larger GIS regional context. This coordination may become very challenging since, typically, the architects and the engineers do not necessarily use geographical coordinated systems in the production of their documents. Most CAD programs are using relative (X, Y, Z) systems to define point location while the engineers and landscape architect are usually using (N, E ,Z) system, the Cartesian coordinates to orient their design, thus, in the world of BIM, by orienting the model to the real world geographic coordinates, engineers could easily coordinate their design with a proposed grading plan and roadwork; the architect could also develop a more intelligent building in conjunction with geographic location (Arbic, 2008).

As a conclusion of what has been discussed above in this section, unambiguous and consistent point location using a geographical coordinate system is the key

concept in the world of GIS, and it is also a key concept to efficiently facilitate how to link the site and building model together. With the accurate definitions of point location, the BIM model could become much more intelligent, so when we import the building model into the site model file, the building should automatically "know exactly where it belongs". This concept would also benefit the computer-aided facility management by a better determination of where best to locate all the facilities.

2.3 Specific Problems need to be solved

Based on the above discussion how BIM and GIS work in the AEC area, the objectives of my research are established. These are:

1. Provide a feasible method using BIM software to create a site-linked BIM model.

2. Discuss the advantages and limitations of applying BIM in site design and construction.

When comes to the topic of BIM for site condition, there are always two questions that need to be concerned. One is how to create a 3D site information model separately from the building model by using real life project data, this process does not only mean to create simple topography from existing site project files, but also to provide a site model that will carry all necessary site information including terrains, orientations, elevations and the underground situation such as ground conditions, drainage and piping system. For example, by using software like AutoCAD Civil 3D and Bentley Inroads, all of the site elements within the site model can be modeled as 3-dimensional intelligent objects. Moreover, with the use of the parametric software engine, changes of design are better coordinated. In the world of BIM, 3D parametric and object oriented software also allows for the same operational characteristics in the model, that is, one small change would make a complete difference, because all

associated parts would be instantly and dynamically updated (Turner, 2007). So a major concern is to find out a way to effectively link the independent building model and site model together, and to what extend should the building model include parts of the site model.

More specifically, the site conditions and related information of interest to this research include:

- Underground Situation

- Logistic Site Condition

- Site-linked BIM model

> Underground Condition: The underground condition of a building project includes its geological characterization as well as information related to existing utilities and equipment such as water line, sewer line, telephone line, MEP line and any existing connection structure like manholes, catch basins and so on. Some fundamental issues of utilities are like types of line, location, cost, maintenance and operation (Martin, 1999). A well-defined 3D site model should address the following issues:

1. Types of Line: On the real construction site, there may be several different types of utility lines that either going above or under the site, each of them may serve different uses of the proposed building, and should be connected with the building MEP systems at different locations. Thus, it is important to clearly design and distinguish different pipe network by using different colors, shapes and distinct icons. 3D BIM model does a good job in improving the visualization of design, which makes this type of work easily achievable.

2. Location: Every element in the existing utility system should be defined by exact location factor, the underground utility network should clearly show the exact location and elevation of every single pipe and duct, thus, whenever there is an excavation going on site, it will help the engineers and contractors to avoid possible collision.

3. Cost: Money would be another big concern with regards to underground utilities. Either the cost of new constructing or the fee of maintenance and repair could be a big issue for the owner. Since most of the pipes are sloped, it would make the cost estimation work slightly distorted if we only have the flat 2D drawings. However, with the measuring and scheduling functionalities that the BIM software provides, it would be quite straight forward to get the exact take off, which would make the cost estimating more accurate.

4. Maintenance and Operation: Also, when it comes to a maintenance and operation problem, the exact location of the corresponding pipe and its type, size, materials need to be found rapidly and easily. That is why we considered BIM for facility management. The BIM model, once created, should be considered as an integrated information system, all the information would be carried on from the initial design, construction to the stage of facility management. In addition the operational characteristics of the utilities, such as the flows, capacities could also be obtained from the BIM model; this would make sure the future day-to-day activities for the building and its MEP systems to perform their intended functionalities.

➢ Logistic site condition: As the construction is in progress, the site condition

is changing all the time from excavation, grading, utilities, paving to later earth refill and finally with the building sitting on it due to different construction milestones. If a 3D building model can be used to show all these logistics adaptations and changes, it would allow the users to better visualize and analyze the as-built BIM data for existing buildings (Woo, *et al,* 2010). Then the question would be, how can a 3D model integrate all the information during the continuous change?

- ➢ Site-linked BIM model: With the defined building model and site model, our next question is how to integrate all the data so it can be used as an entire information source in the future? A possible answer is to create a 3D site-linked model. This requires both the theoretical knowledge and the software technological support to do it. Since some BIM software support the functionalities of phasing and scheduling, the 3D site-linked BIM model can be realized by using different software such as Revit, AutoCAD civil 3D, ArchiCAD, Bentley products and so on. Another issue is, since the site model and the building model are usually provided by different parties in the design and construction team— Architect and Civil engineers, the interoperability between different software could be an issue, coordination need to be done before linking the two models together, so that the building model would know exactly where the location is. This is further discussed more specifically in the following sections.

2.4 Current Application Issues & Technology Support

The specific approach on how to better integrate the site and building models has not been clearly defined yet. In some news and reports of former case studies, a general

method has been mentioned about how to create a site-linked 3D building model, but none of them are specific enough.

To provide the functionality of creating the site-linked BIM model, many software vendors have developed different kinds of related products. Autodesk Inc., as one of the biggest multinational corporation that focuses on computer-aided design software, developed both the AutoCAD Civil 3D and Autodesk Revit and proposed different approaches to address to solve this problem. AutoCAD Civil 3D, as quoted from Autodesk, is a software that aimed to provide "*a BIM solution for civil engineers that helps project teams to explore more what-if scenarios with visualization and analysis tools that allow interactive simulations*"(Autodesk, 2011). With its standout functionalities such as site survey, building surfaces from traditional data, grading, laying out sanitary and storm drainage systems, breaking and joining existing pipe networks, Civil 3D can always be used to create a 3D site model. Much more important, comparing to solely 3D building model, with its' interoperability with both Google earth and Autodesk Revit, the site-linked 3D model can be realized. Thus, AutoCAD Civil 3D was considered as one of the most common software to create a site model, while Revit was used for Architectural/Structural model. Autodesk also provided plenty tutorial and training materials for all of its products.

In addition, there are some more methods to create a site-linked BIM model. One is to use Graphisoft's major product, ArchiCAD. Although this software is not designed for Civil Engineering, it could still be used for site modeling, and the software itself has a good interoperability with other BIM tools.

The other one is to use products from Bentley systems. Comparing to Autodesk, Bentley is more dedicated to sustaining infrastructure, it provides solutions for not only buildings, but also bridges, transit, utilities, roads, water and wastewater. It has

Bentley Architecture for building design and documentation, and for site design, it has the InRoads Site Suite, which was designed especially for site development and revitalization.

However, although the software vendors have developed the corresponding products for both site and building design, the interoperability and coordination among different software has not been clearly defined and tested; and the specific procedure of integrating site and building together has not been fully investigated. Thus, based on the BIM software that I explored above, further discussion would focus on the methods of using different software combination to achieve the integration of building and site model. The specific procedures of each method would be presented in the following section.

3. Technology Support — Feasible Methods to Create a Site-linked 3D Model

To create a site-linked BIM model, one needs to first seek for current technology support. As previously stated in this report, there are currently three major software vendors who provide technology resources for this purpose: Autodesk Inc., Bentley System and Graphisoft SE. This chapter reviews the approaches that can be followed to create the site-linked BIM model by using different software provided by these vendors. This is done through the following three steps:

1. Find out the corresponding BIM software for both the site and building modeling.

2. Discuss the software interoperability with other BIM tools.

3. Provide all the feasible methods of creating a site-linked building model.

3.1 BIM Tools & Interoperability

Three vendors provide some corresponding BIM solutions for Building and Site design. Autodesk, Inc. has Revit for building modeling and Civil 3D for site modeling. As described by Autodesk, Revit Architecture building design software was built for BIM. And it could help the architects and designers to develop high quality designs, to better capture and analyze concepts and versions through design, and to produce a better coordinated documentation for construction (Autodesk, 2010). On the other hand, Civil 3D is a BIM solution for Civil Engineering design and documentation. The software is suitable for transportation, land development and water resources engineering project, it is also the most commonly used software for site modeling in the US industry.

Bentley system provides Bentley Architecture, which serves the building design like Revit Architecture. For site modeling, InRoads Site Suit runs on Microstation and AutoCAD, provide the powerful functionalities of site, survey and drainage, as well as the cohesive solution for land development and site modeling (Bentley 2011); PowevCivil offers civil engineers and designers a flexible 2D/3D tool for land development and site model, it is suitable for commercial building sites, campuses, as well as the drainage utility projects (Bentley, 2011).

Graphisoft does not have as many products as the other two software vendors do, its core product, ArchiCAD is mainly developed for Architectural and structural design; however, this BIM tool does have some features that would enable some simple site design.

For interoperability, since all the BIM tools for building and site model support the CAD DGN and DWG format, theoretically, the model could be imported and exported smoothly among different software. However, to get a better performance of the model, some integration software could be used such as Navisworks and Bentley Navigator. This would integrate the pieces of model made by different software together; provide better control and coordination of the overall project outcome. Table 1 below contrasts the operational characteristics of the software produced by the three vendors.

Table 1: BIM Tools & Interoperability

Vendors	Purpose	BIM Tools	Supported Format
Autodesk Inc.	Building Model	Revit Architecture/Structure	CAD Formats: DWG, DXF, DGN, SAT; DWF/DWFx; ADSK; Image; IFC; ODBC; nwf
	Site Model	AutodCAD Civil 3D	DGN, DWG, DXF, DWS, DWT, DWF, Nwf
	Integration	Naviswork	NWD, NWF, NWC
Bentley System	Building Model	Bentley Architecture	DGN, DWG, DXF,STEP, IGES
	Site Model	InRoads Site	DGN, DWG
		PowerCivil	DGN, DWG, XML data, PDF
	Integration	Bentley Navigator	DGN, DWG
Graphisoft	Building Model	ArchiCAD	DWG, DGN

3.2 Feasible Methods

3.2.1 Method 1 — Autodesk Revit Architecture

Autodesk Revit Architecture, as described by Autodesk, "*is a design software helps architects and designers capture and analyze early concepts, and then better maintain designs through documentation and construction*" *(Autodesk, 2011)*. In the real world design, Revit Architecture is mainly used to design buildings - walls, floors, ceilings, doors. However, very frequently, the architects would be asked to add site and structural information into the model, which required the software itself, provide tools to create topographic surface for site work.

Revit Architecture provides the very easy-to-use tools for modeling and parametric design, not only for the building itself, but also for the site condition. To simplify the

process and reduce the unnecessary cost of using different software products, the first conceptual method this paper is researching on is the use Revit Architecture site tools for the sole purpose of realizing our goal — to provide a site-linked 3D building model.

For the site model, Autodesk Revit Architecture massing and site tools enable the user for conceptual design and put the building in a context of landscape environment. The toposurface in Revit can be created either by importing Google Earth Picture or drawing contours and points directly. It also has the functionalities of split or merge the surface, grading region, draw property lines, create building pad and other site components such as parking lot, daylights, trees, plants and so on. In addition, since most of the 3D building models are created by Revit Architecture/Structure, simply import or link the two Revit file together will get you the final site-linked 3D model (Greenwold, 2007). The process is simple as the following picture shows, create two separate files in Revit Architecture, one is for building model, the other is the site model, then one choose to either link or import the two Revit files together.
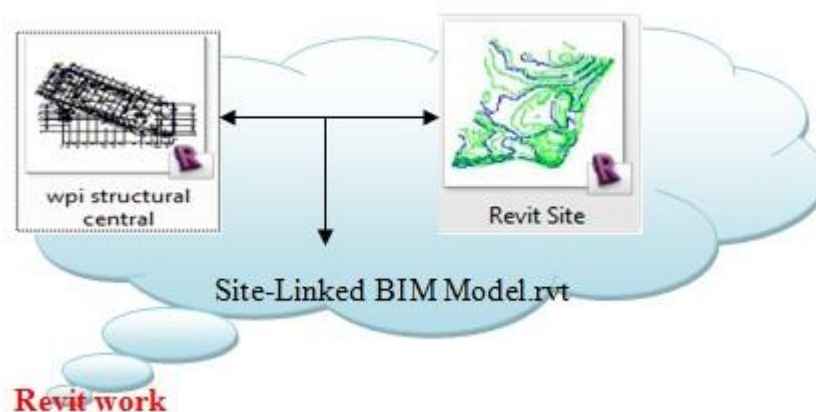

Figure 2: Method 1 — Revit Architecture

However, one big drawback of using Revit Architecture is that it is not very efficient when it comes to place and locate underground utilities. Since there is no utilities

menu in Revit Architecture, the model of site work becomes very limited, theoretically, the pipe work can be done by created all the new elements as families, however, it would be very time consuming and error-prone. Thus, if the proposed project has a very complicated existing site condition, Revit Architect probably would not be the best choice for the architect and engineers.

3.2.2   Method 2 — Revit Architecture & AutoCAD Civil 3D

Another feasible approach is to use AutoCAD Civil 3D to create the site model and then link it with the building model either in Revit Architecture or AutoCAD Civil 3D. Unlike Revit Architecture, the major aim of AutoCAD Civil 3D is to provide the BIM solution for civil engineering rather than architectural design. As quoted from Autodesk, "*the software focus on delivering higher-quality transportation, land development, and environmental projects faster, explore design ideas and analyze what-if scenarios to help optimize performance before projects are built (Autodesk 2011)*". The intention for the use of this software determines the built-in features to provide better site tools to model the site conditions, Civil 3D is functional in modeling grading and intelligent pipe network, pipes and structures can be changed simultaneously by using graphical or numerical input, and interference checking tool would find any collision between the pipe system or pipe and the excavation for the user. In other words, comparing to Revit Architecture, AutoCAD Civil 3D is more functional for underground utility design. And since Revit supports the integration with AutoCAD Civil 3D, the site data can be transferred between these two software's efficiently, which means the 3D Revit Building model can be linked with modeled site eventually.
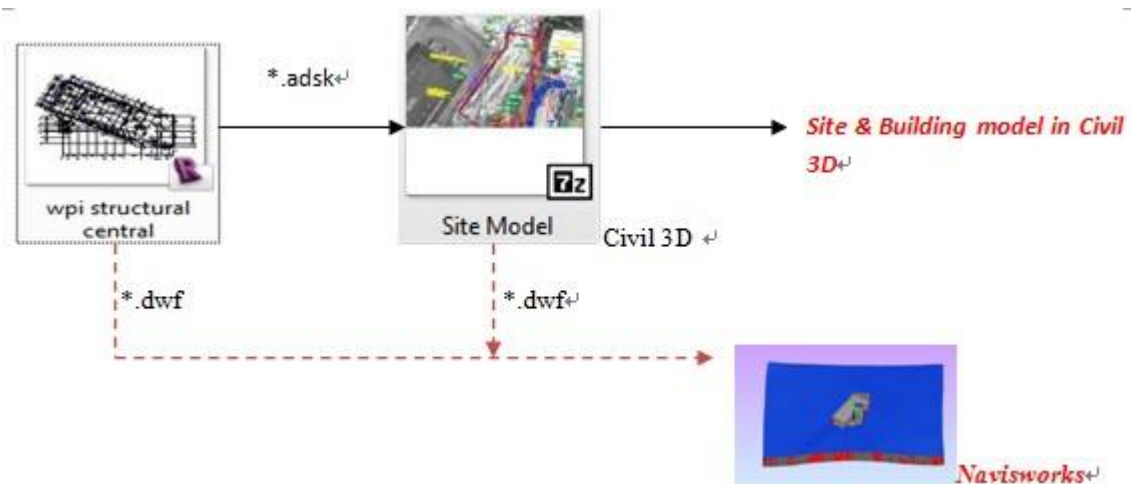
Figure 3 Method 2 — Revit Architecture & AutoCAD Civil 3D

However, standing from the visualization point of view, Civil 3D may not be as good as Revit. To achieve a better visualization of civil engineering projects created in AutoCAD Civil 3D, Navisworks could be considered (see Figure 3 above). Export both the Civil 3D file and the Revit file as *.dwf format, and then merge the two flies as one single model in Navisworks, this would provide a better visualization as well as reduce resources of the models and improve coordination among different users.

3.2.3   Method 3— Bentley Products

The third method is to use Bentley products. This method is quite similar to method 2 (see Figure 4 below). InRoads/Power Civil is playing the role of Civil 3D while Bentley Architecture is taking Revit Architecture's place. One marked feature of Bentley, comparing to Autodesk's products, is that it dedicates in delivering solutions for the infrastructures rather than buildings. Specifically, Bentley products provide efficient solutions for bridges, factories, roads, rail and transit. It also provides solutions for campus design and operation, which is comprised of sites, utilities,

buildings, roads, paving and assets. With its core design tools: Inroads site, power

civil and Geopak site, Bentley offers a complete solution for easy site modeling,

survey data management, digital terrain modeling, water/sewer line layout and

analysis, street design and so on. Similar to using Revit and Civil 3D, the process is to

use Bentley Architecture to create the building model, and then according to the

project information, chose either InRoads or PowerCivil to create the Site model, than

link them together. Bentley Navigators could be applied or not to integrate the two
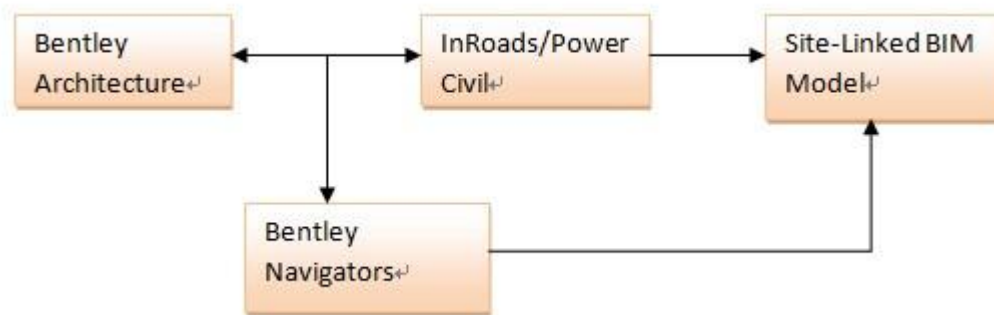
models together.

Figure 4: Method 3 — Bentley products

3.2.4   Method 4 — ArchiCAD & Other BIM software

The fourth method is to use ArchiCAD to create the site model. ArchiCAD, as

architectural BIM software developed by the Hungarian company Graphisoft, could

be integrated with other BIM applications including Autodesk Revit and Civil 3D.

Although the mesh tool in ArchiCAD is not intended for Civil Engineering, still, it

could be used to present the virtual building by modeling terrain of the site model. To

create a topographic surface, one can either start out with a Scanned Image or in the

form of a civil engineer's DWG files, import and simplifying the contour maps,

creating solid site model with the mesh tools from the contours (see Appendix 1 for

specific steps). One can also add roads to the site, develop terrain and paving meshes, modeling foundations, cut a hole on site as excavations and so on (Graphisoft, 2011). And since ArchiCAD has good file format compatibility, the site model could be brought into other BIM software so that the building model and the site model could be linked together (see Figure 5 below). Some of the choices are, export the site model as AutoCAD's Vectorial DWF format, which is the supported format of Revit; or export it as MicroStation's DGN, which would incorporate with Bentley products (Graphisoft, 2011).
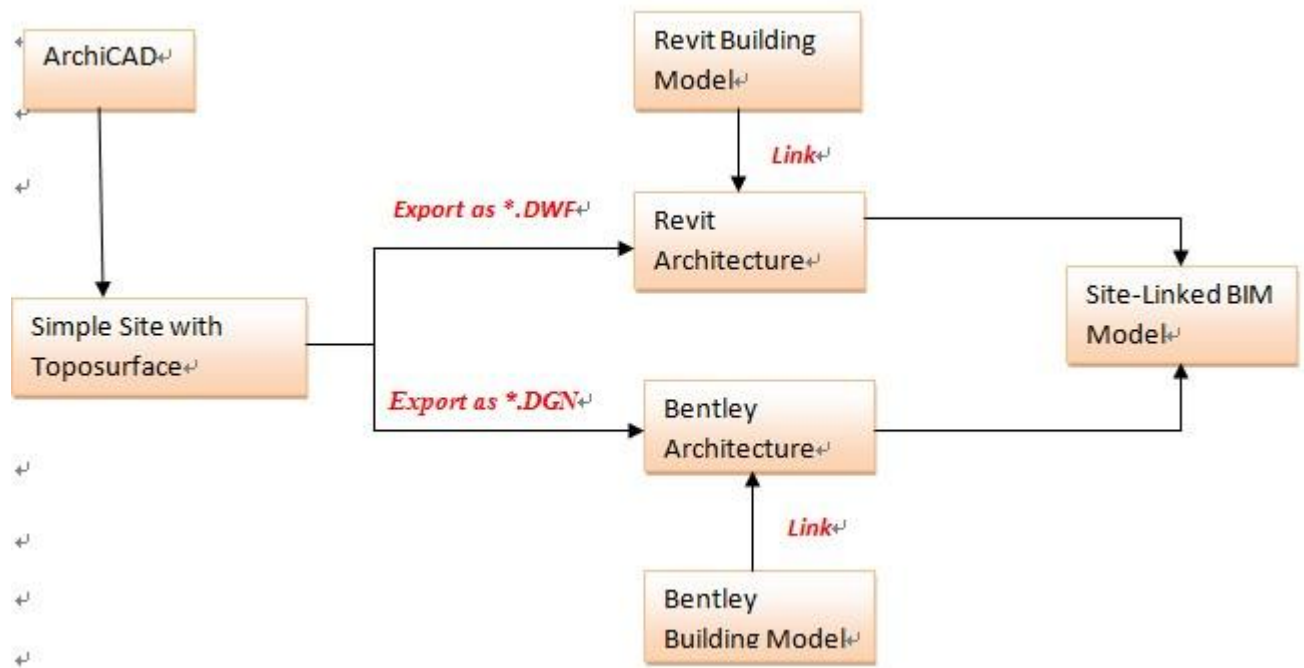

Figure 5: Method 4 — ArchiCAD & Other BIM Software

In conclusion, theoretically, all of these four methods could be applied in achieving a site-building integrated model. However, since they are slightly different in design functionalities, supported format and interoperability, the method should be chosen under specific project circumstances. Method 1 and Method 4 are proposed to use single software for modeling both building and its' corresponding site, these two

methods, from the aspect of software investment, would be more economic; the procedures are simpler since the two models could be created as the same format, which would reduce some orientation and interoperable issues. However, the common drawback of Revit Architecture and ArchiCAD is, both of these two software are developed mainly for building design, they do not have the functionalities for site design more than a simple topographic model. Therefore, if the project has a complicated site condition, these two methods would not be considered as the best choice.

Comparatively, method 2 and method 3 are using two different applications to model the site and building separately, these would enable that more details could be contained in the site model, the site model could provide the owner, the designer and the civil engineers more detailed information, not only the topographic surface, but also the soil type, landscaping, access roads, ground conditions and the location of site utilities. Yet, by using more than one software product, the interoperability issues need to be taken into account. The model needs to be imported and exported as required format, the orientation needs to be coordinated before the integration, and to achieve a better integration and visualization, Navisworks and Bentley Navigator could be involved within the procedure.

4. Case Study

One case study was developed to explore and understand the details that involved in creating a new site model and link it with the existing 3D building model. The project selected for this case study is the WPI new sports & recreation center. It is currently being constructed on the west side of WPI campus between Alumni Field, Morgan Hall and Harrington Gymnasium.

The case study focus on two major parts of work, one is to explore how to create a site model by using appropriate software and procedure, the other is to figure out how to link the site and an existing building model together. This project has a very complicated ground and underground conditions, there are a lot of underground utilities need to be modeled. Thus, for the first part of work, according to the discussion of technology support in Section 3, method 2 — Revit Architecture and AutoCAD Civil 3D, conjunction with Google earth were used as the major computer software to develop the model of the site. As for the second part of work, an existing BIM structure building model created by Cannon Design Inc. was brought in Autodesk Civil 3D to complete the sit-linked model.

The objectives of this case study are to address the following major issues:

- Provide a detailed feasible method to create site-linked BIM model by using Revit Architecture and Autodesk Civil 3D.

- Compare the advantages and disadvantages of using different software to develop the toposurface and to define the underground site conditions.

- Understand how many details can be involved in the site model and how this BIM information can be used during the design and construction process, and further used for the future facility operation maintenance.

- Explore the potential problems when link the building model and site model together.

- Provide corresponding solution to the problems we met during the whole developing process.

This case study would test the feasibility and provide a more specific procedures of using Revit Architecture and AutoCAD Civil 3D to create a site-building integrated model. The detailed process will be discussed and analyzed in the following section.

4.1 Previous Related Study at WPI

At first, this case study was developed to provide an alternative design to the earth-retaining structure for excavation of the Worcester Polytechnic Institute new Sports and Recreation Center to resist lateral loading during construction by a WPI Major Qualifying Project (MQP) group. During the process of looking for a solution, the use of Building Information Modeling was mentioned and considered to present a visual aid of the building's location on the WPI campus and to show the different phases of excavation for the building by creating a construction site model (Moynihan, *et al.,* 2010). As Figure 6 and Figure 7 shows below, they created a toposurface with a building pad on it, this simple model, although does not contain many details, shows contour lines and elevations which were used to add 3 dimension to the site, and the building pad is where the excavation took place. However, since they are using BIM mainly for a visualization purpose, the work has not really been done rather than a simple 3D Revit model with a topographic surface.
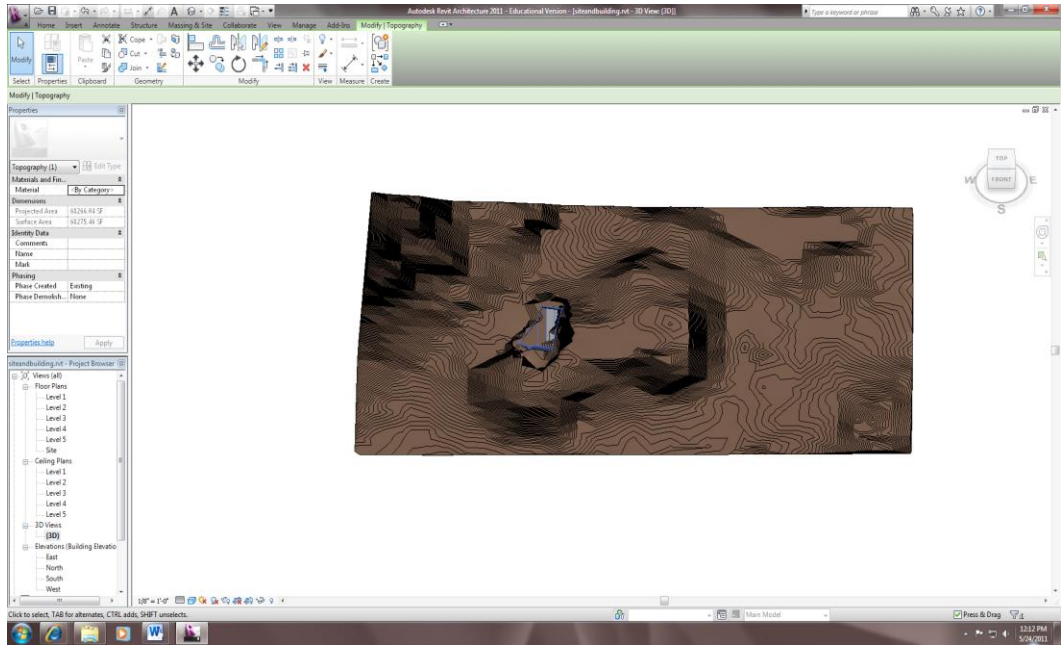
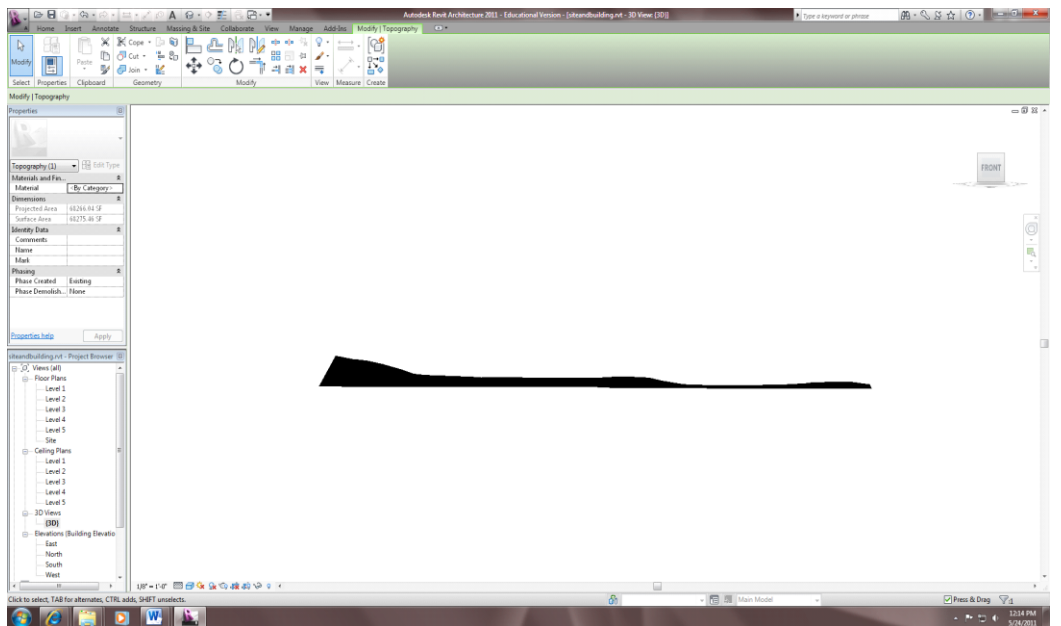**Figure 6 : MQP Work – Terrain Model from Front 1**

Figure 7 : MQP Work – Terrain Model from Front 2

As a result of this work the following was found with regards to the site-building model integration:

- The Google earth picture of the site had to be exploded in civil 3D before brought into Revit so a 3D topsurface can be reconstituted within Revit. If you explode the picture in REVIT, the top surface becomes flat automatically.

- Another issue is related to the elevation. When we tried to link the building with the site; the elevation of the building will be imported as well, and since the basic elevation (0'00'') of the site has been created automatically by the software, you may have two different elevations at the same time, and this would become an issue when you try to cut a pad within the site model in Revit.

- Also, adjusting the location and direction (orientation) of the building is still quite problematic because when you import the building within the site file, you can either rotate the building and site as a whole together, or you can rotate the building solely, but the site model, as the original file, cannot be rotated solely.

Thus, addressing these issues became part of this research, which aims to figure out a feasible way to create a site model that shows all the underground site condition around the proposed building. The next section includes the general project information, the process of defining the existing problems, proposing solution, choosing appropriate software, specific working method, and the final result.

4.2   General Project Information

The rationale for the WPI new recreation and sports center can be summarized as follows: *"On October 30, 2009 the "WPI Board of Trustees voted unanimously towards the construction of the 140,000 square-foot Sports and Recreation Center"* (WPI, 2009). The proposed building is currently being constructed and it is located on the west side of the WPI campus between Alumni Field, Morgan Hall and

Harrington Gymnasium. The new facility, after completed, would contain a natatorium, a fitness center, a four-court 29,000 square-foot gymnasium and an indoor three-lane jogging track, as well as the handball courts, dance studios and meeting spaces for the stuff of the Department of Physical Education, Recreation and Athletics (WPI, 2009). Other specialized spaces include an indoor rowing tank, racquetball and squash courts, well-equipped locker rooms and a training and rehabilitation suite at field level. Aside from all of the athletic commodities, the new building will also contain a robot pit to accommodate for the Robotic competitions, in direct correlation with the new and growing Robotics major WPI offers. A corridor will connect the existing Harrington Auditorium to the new building, creating larger event space for career fairs, admissions open house, alumni events and conference (Moynihan, 2010)." The issues related to this research were further explored in the context of this facility.

During the design and construction phases, there is a lot of information coming from different parties of this project. WPI is the owner of this project, cardinal construction is the owner's representative, and they have the basic requirement and expectation of this project. The proposed building is designed by Cannon Design Inc., and it is planned to be completed by Gilbane Inc., a leading building firm that is providing full construction management as well as facilities-related services. Vanasse Hangen Brustlin is the civil engineer and Haley Aldrich is the geotechnical engineer. So as Figure 8 below shows, there are many models, reports, as built information from all of these participants. That is why BIM was considered by the MQP group at the first place, to help facilitate communication between different parties. Further application of BIM in defining site conditions would be discussed in the following section.
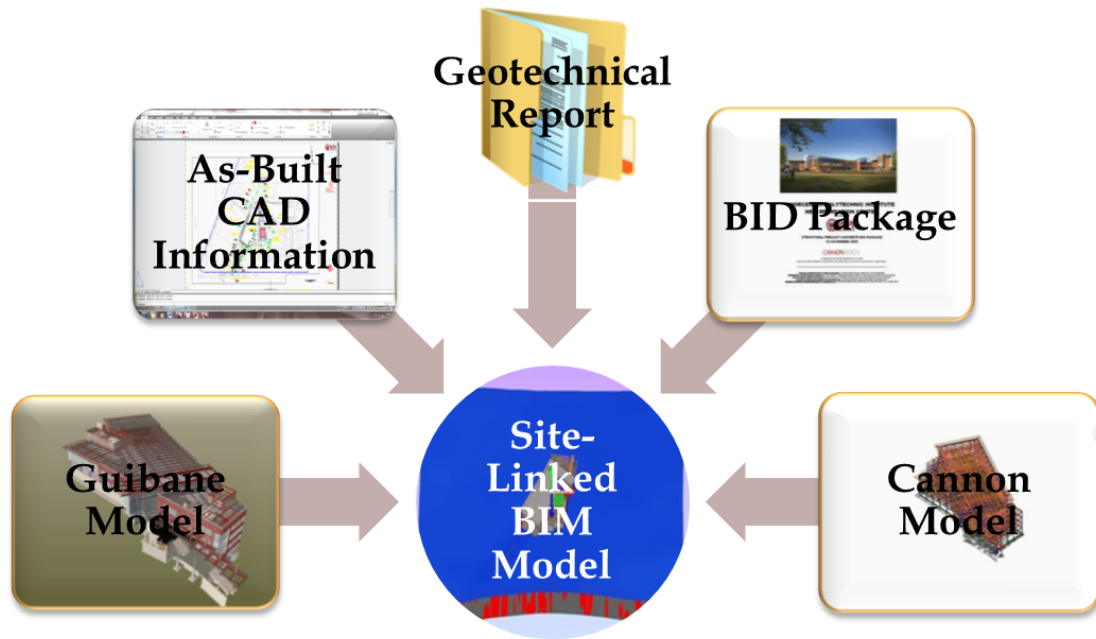
Figure 8: Case Study – BIM as Intergrated Information Resource

4.3 Existing problems

There are two major issues during the construction of this project.

● Underground water table is high

● Location of existing underground utilities

High Underground Water Table: One issue that the construction team cares a lot is that the underground water table is very high at the construction site, thus, the drainage system need to be set up before the excavation could take place. In addition, the underground condition is complicated since there are a lot of pipes, manholes, telephone lines, gas lines and so on around the building, and if the information of these underground situations is unknown, it would make the further construction become risky and difficult.

Location of Existing Underground Utilities: The construction team has some site

information on hand such as the soil borings, civil drawings that shows the general proposed site information including grading, drainage, erosion control plan, utility plan and site details, they also have the Auto CAD design and construction drawings that show the as built site information produced by the excavation contractor (Figure 9). However, none of these documents are 3D format, they are either notes, paper drawings or 2D CAD drawings, these documents carry the necessary site information for civil engineer and construction team, however, it is hard to tell from these descriptions and drawings where the exact corresponding 'Z' coordinate location of each item is. The real construction site is not like a flat drawing, it is 3-dimensional, every single pipe, catch basin, manholes has its location, not only defined by the simple (x, y), but also the "z" which decides its elevation. And without knowing the elevation, none of these items can be really defined on site. Hence, this case study, based originally on the work that has been done by the MQP group, has continued researching on how to convert this 2D information into a 3D site model, and finally deliver a site-linked 3D building model that carries all the necessary information that can be shared by different parities during construction process.
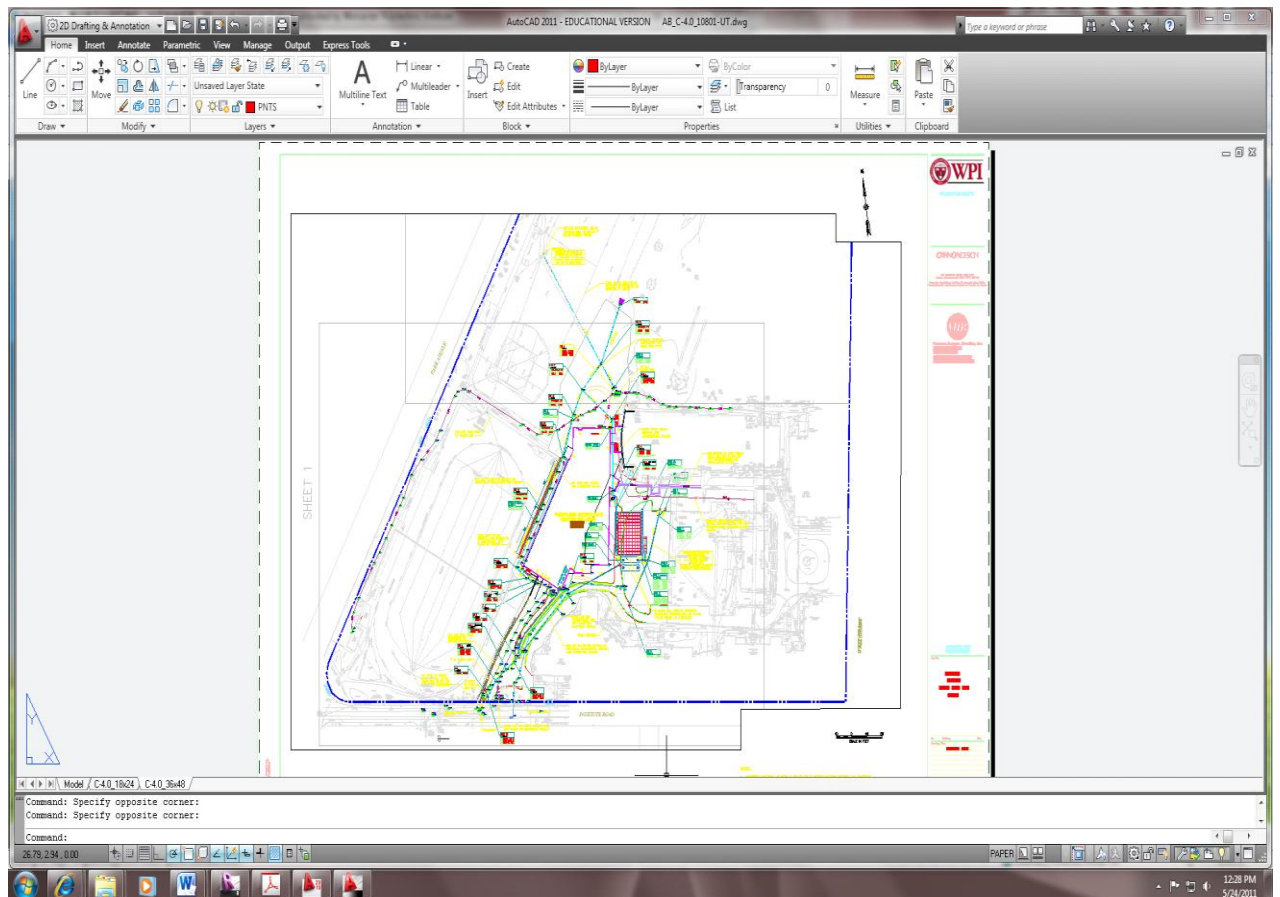
Figure 9 : CAD Drawing – As Built Utility Information (Provided by Gilbane Inc., 2011)

4.4 Specific Concerned Issues & Proposed Solutions

To start creating a site linked BIM model for this project, three major steps need to be followed in order. First step is to choose the appropriate software according to the current accessibility, then compare and decide the procedures of creating a site model and link it with the existing building model, the last step is figure out what the specific issues of this project are and provide the corresponding solutions. An expanded discussion could be found in the following sections.

4.4.1 Selection of the Appropriate Software

To create a 3D site-linked building model, the first step is to convert 2D site drawing

into a 3D topographic surface, which would show the terrain of the existing site where the construction would be developed. This simple model, even without any underground information like pipes and ducts, can still be used by architect, engineer and also the construction team to get a general idea of how the planned site look like, where the excavation would probably take place, which place can be considered to store materials, equipment, and etc. Also, this sketchy model is the foundation of the following steps and will be carried through the construction phase for further development.

Based on what has been discussed in the prior chapters, there are several ways to create a toposurfarce, either Revit, AutoCAD Civil 3D, InRoads and ArchiCAD can be used to accomplish this task. The MQP group chose to use the process of "Google Earth-Civil 3D-Revit Architecture" to realize this task, yet, in this case, AutoCAD Civil 3D over Revit Architecture has been chosen to accomplish most of the site part for the following reasons:

- Less Software Involved & Simpler Procedure

  Generally speaking, there are two ways to create a 3D toposurface. One is to use Civil 3D to explode the Google earth picture and then bring it into the Architectural Revit, then in Revit screen, click the tab of Create toposurface, select the corresponding lines that you need to display(C-TOPO-MAJR, C-TOPO-MINR in this case), and then you will have the up and down toposurface in the 3D view (Figure 10).
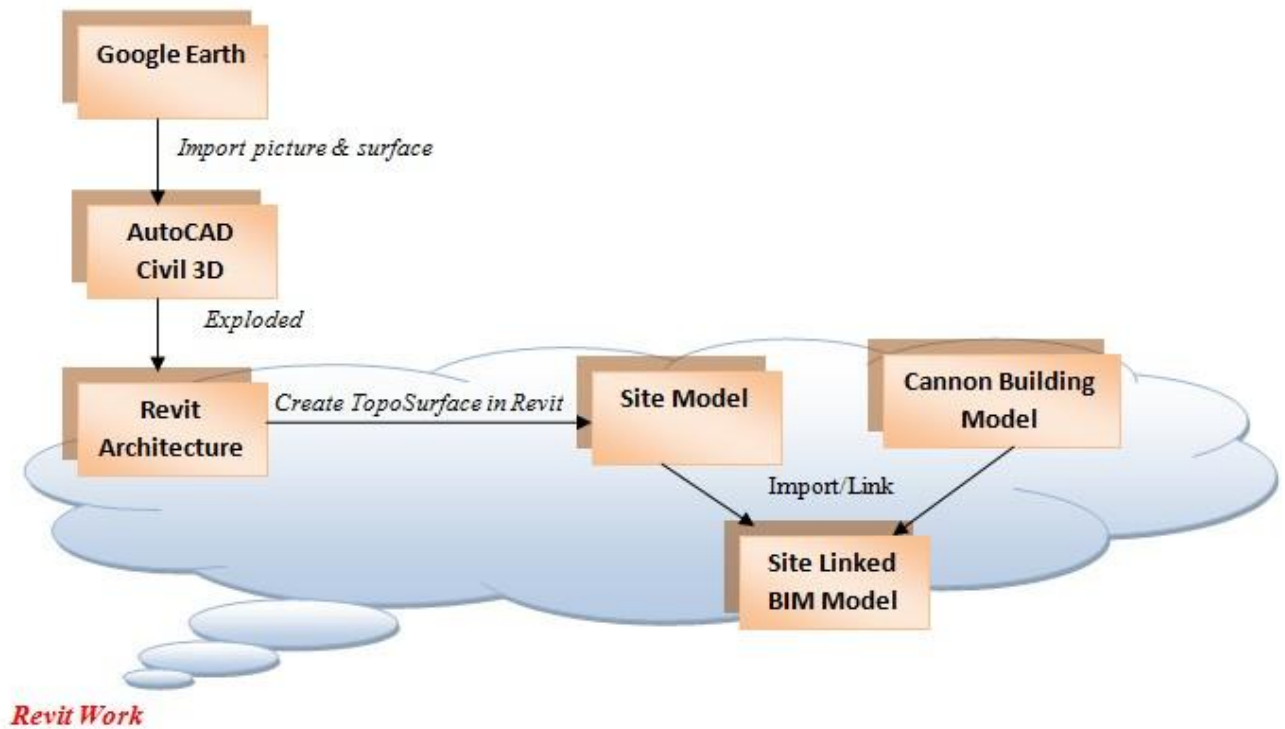
Figure 10 : Procedure 1 – Create Toposurface in Revit

The other method (Figure 11) is to import the site picture and surface directly from Google Earth to Civil 3D, define the insert point (x,y,z) to put the site, it would appear as a 3D site automatically in Civil 3D. This second method was selected, considering to bring the Revit building model later into Civil 3D, by using this method, most of the site modeling work can be done in Civil 3D, rather than Revit, which is much more efficient comparing to Revit.
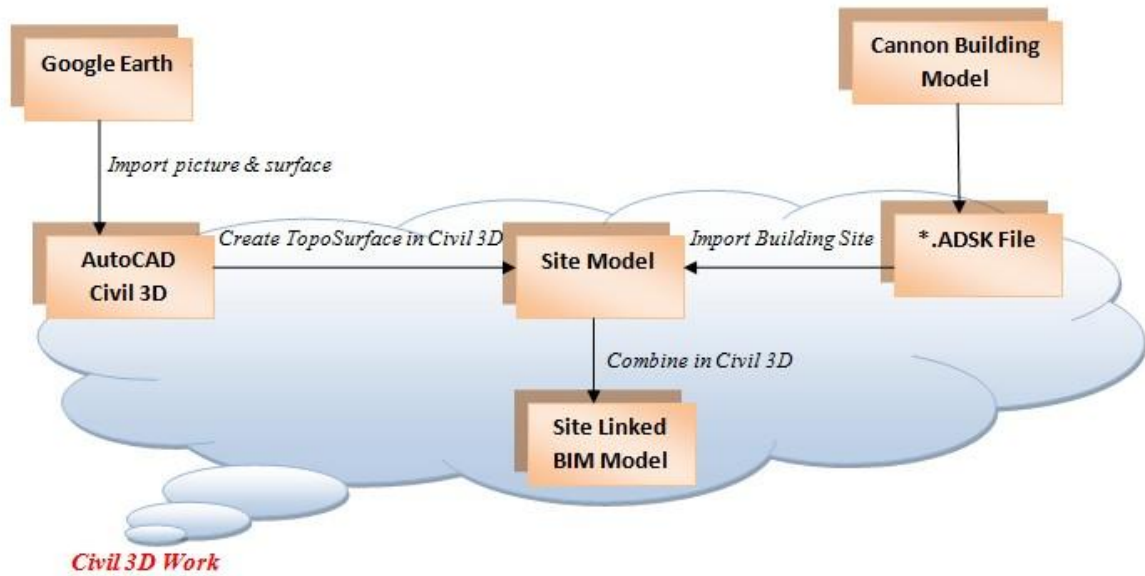
Figure 11 : Procedure 2 – Create Site Model in AutoCAD Civil 3D

- More Powerful functionalities

Both Revit and AutoCAD Civil 3D has been developed to have powerful functionalities for site design and landscape. However, each of them has different strength and limitation in different design areas, the following table was prepared depending on my own using experience and the information provided by Master Graphics, Inc. in 2008.

Functionalities Comparison: Revit Architectural Vs. Auto CAD Civil 3D
- ✓ Tool Available
- Tool Not Available

Functionalities	Revit Architecture	Revit MEP	Auto CAD Civil 3D
View			
3D	✓	✓	✓
Modeling			
Piping			
Pipe		✓	✓
Structure		✓	✓
Pipe Accessories		✓	✓
Plumbing Fixture		✓	✓
Site			
Toposurface	✓		✓
Subregion	✓		✓
Split Surface	✓		✓
Merge Surfaces	✓		✓
Grading	✓		✓
Property Line	✓		✓
Site Components	✓		✓
Label Contours	✓		✓
Tools			
Earth Volume Calculation	✓		✓
Heating & Cooling Loads		✓	✓
Check Duct Systems		✓	✓
Check Pipe Systems		✓	✓

Table 2: Functionalities Comparison: Revit Architectural Vs. Revit MEP Vs. AutoCAD Civil 3D — based on graphic from Master Graphics, Inc. 9/23/2008

According to the information provided in the table above, apparently, Autodesk Revit Architecture provide a better appearance of the 3D model, building pad can be easily added into an exist toposurface, the 3D view including the landscape is more vivid and realistic. However, it has an obvious limitation in defining the underground site condition. Pipe system, which is the key point in this case study, cannot be defined in Revit Architecture. Comparatively, Revit MEP is more suitable for mechanical,

electrical and plumbing (MEP) design, yet, this software is usually used to define the within building MEP system, not the underground existing one. So it lacks the functionalities in defining the exit site condition such as the surface, contours, grading and other possible site components. Thus, overall speaking, although AutoCAD Civil 3D is not perfect in the part of 3D view, it has some standout features in defining the site components as well as an existing underground MEP system, plus, it provides various tools to calculate the excavation volume, and check the pipe system.

4.4.2 Define Existing Underground Site Condition— Utilities

According to the set of drawings and the 2D as built CAD drawing, the underground utilities condition that may affect the construction can be divided into the following categories:

- Pipe Drainage System

- Sewage System

- Electrical Line

- Telephone Line

- Gas Line

> **Dewatering:** Before the construction took place, a total of eight test borings, designated B101 through B109 were conducted at the project site by Seaboard Drilling, Inc. in October 2008. As Figure 12 shows below, the groundwater observation wells were installed in test borings B105, B106 and B109 to

permit observation of stabilized water levels. According to the Geotechnical report prepared by Haley & Aldrich, Inc. Boston, Massachusetts, the groundwater was observed at a depth below grade of 8.5 to 21 feet (EL. 512.5 to EL. 534), and in advance of excavation, to prevent disturbance of foundation bearing soils and potential excavation instabilities, the water level should be lowered and maintained in the soil to minimum of 2 feet below the excavation level (Haley & Aldrich, 2008).
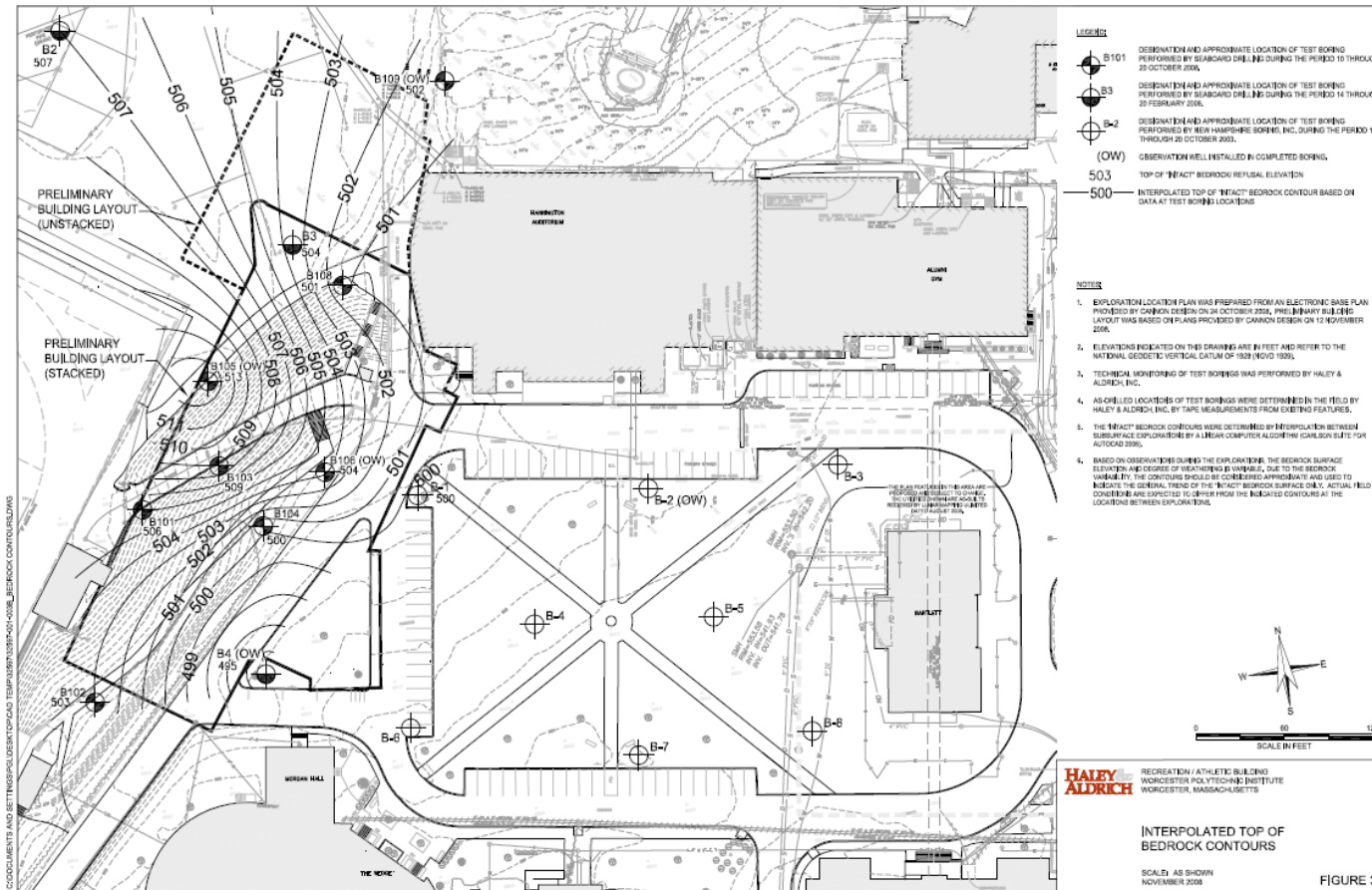
Figure 12 : Groundwater observations wells plan by Haley & Aldrich's Geotechnical Report

As the 2D pdf drawing C-3.0 (Figure 13 below) and the CAD drawing (Figure 9) shows, the blue line indicates the drainage line. Mainly, there are two long drainage pipes around the building, as well as 13 drainage manholes, several catch basin, water quality unit and a storm water detention system on site that connect different part of the pipes. In the CAD drawing, we can find out one pipe starts from the southwest corner of the building, goes all the way up along the west side of the foundation and ends at the north side of the building as manholes, the pipe that coming from the drainage manhole 15 goes into the building. The other pipe starts from the very south, connects with a storm water detection system on the east side, and then goes up along the building and connects with the first pipe at the north side.
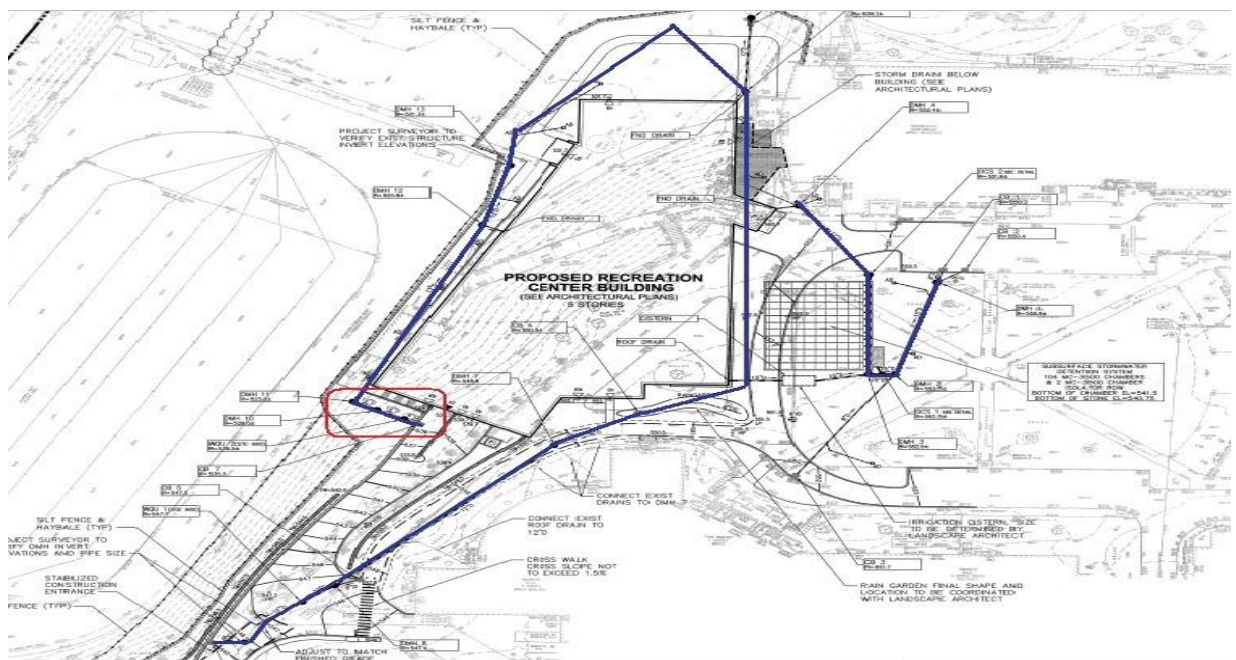
Figure 13: Structural Precast Concrete Bid Package C-3.0 (Cannon Design)

As Figure 14 shows, the elevation of each drainage manhole is marked in a label next to each dot; however, since there is no 3D view of the drawings, it is

hard to tell the exact location of each pipe and connection part, where the pipe comes in the building, where it ends, and if there is any interference that may affect the excavation and construction.
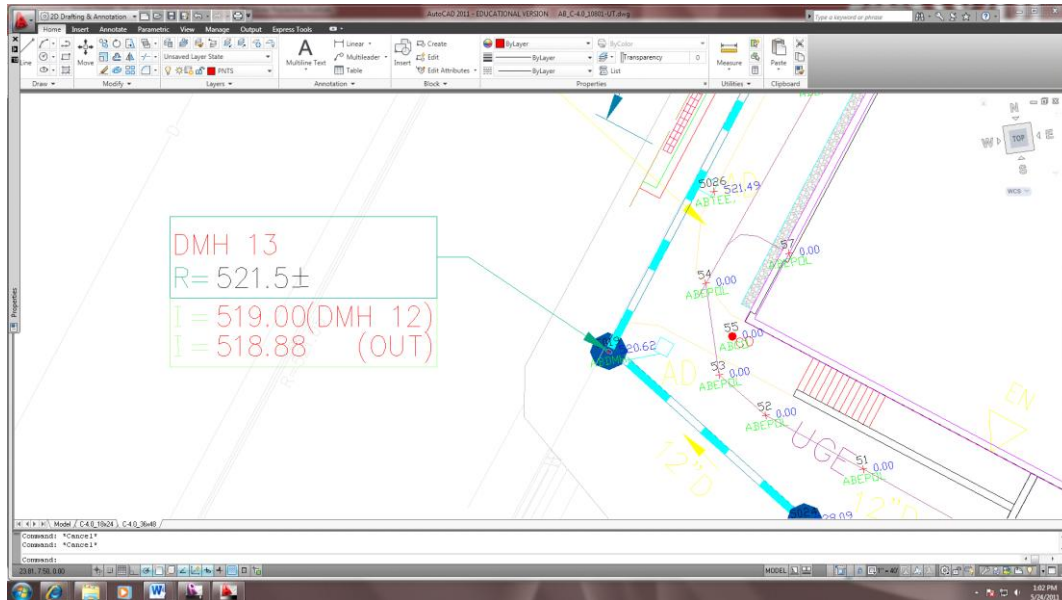

Figure 14: Example of Label from CAD as-built Drawings

From the engineer's point of view, to completely understand the drainage pipe system in this project, with only the as built CAD drawing is not enough, several information from various source need to be considered, the label in the CAD Drawings as the figure above shows, indicates the Rim Elevation of the Manhole, the invert elevation connecting with 2 different pipes, and the direction of the pipe. However, to learn further information like the pipe materials, the diameters of different pipe, the shape and height of the manholes, one need to go to the Civil Paper drawings, and find out these information from numerous notes on the front page.

In addition, without reading the notes for utilities in the front page (Figure 15), one can never tell the materials, diameters of the pipes directly from the flat drawings. Those are all the problems that I tend to resolve by bringing the

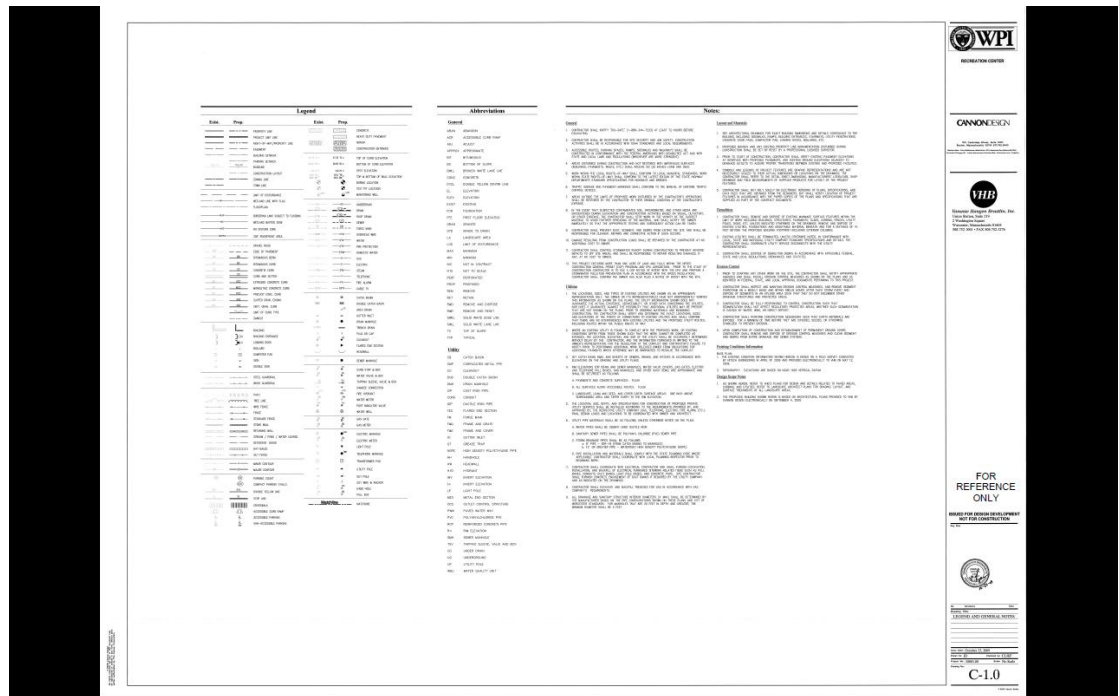concept of BIM and 3D model into this case.

Figure 15: Structural Precast Concrete Bid Package C-1.0 (Cannon Design)

All the information that an MEP/Site engineer may need, as we mentioned above, could be carried by one single 3D site model, as the figure 18 shows, one can choose to hide or simply display the pipe without the label, so that the whole system would seems quite clear and intuitionistic, and if more information is demanded, simply click on the item, a label will appear that gives out the item's name, shape and size. As the figure 16 shows for example, the manhole that was selected is a drainage manhole No.13, 48 inches, cylindrical structure. And more information can be obtained by clicking the properties, the pumps out diagram (Figure 17) gives out the detailed information of the selected item. Take the pipe 14 for instance, it is a 12 inch HDPE pipe and the property window shows the pipe slopes, invert elevation, start and end elevation.
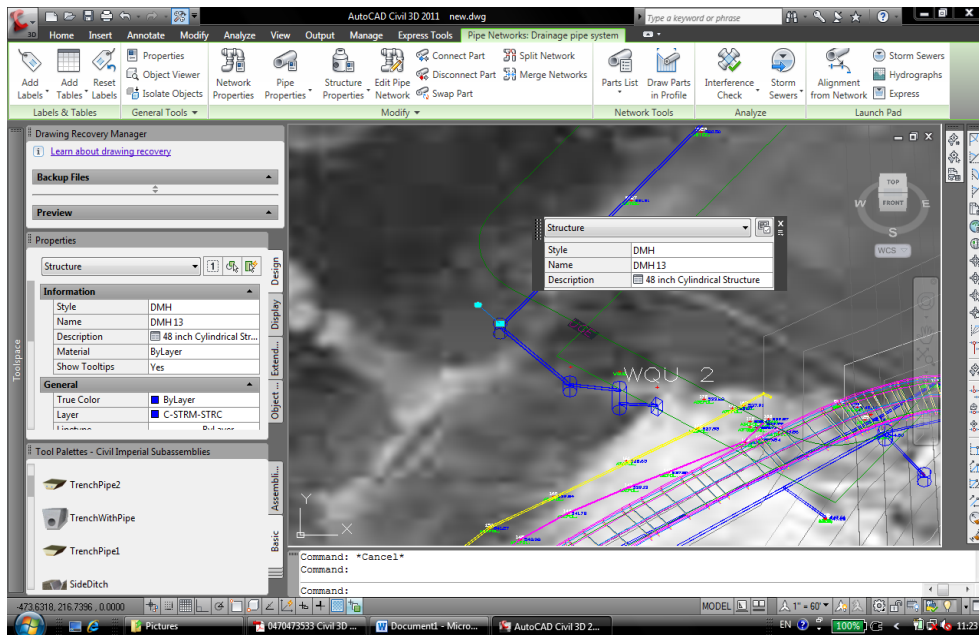
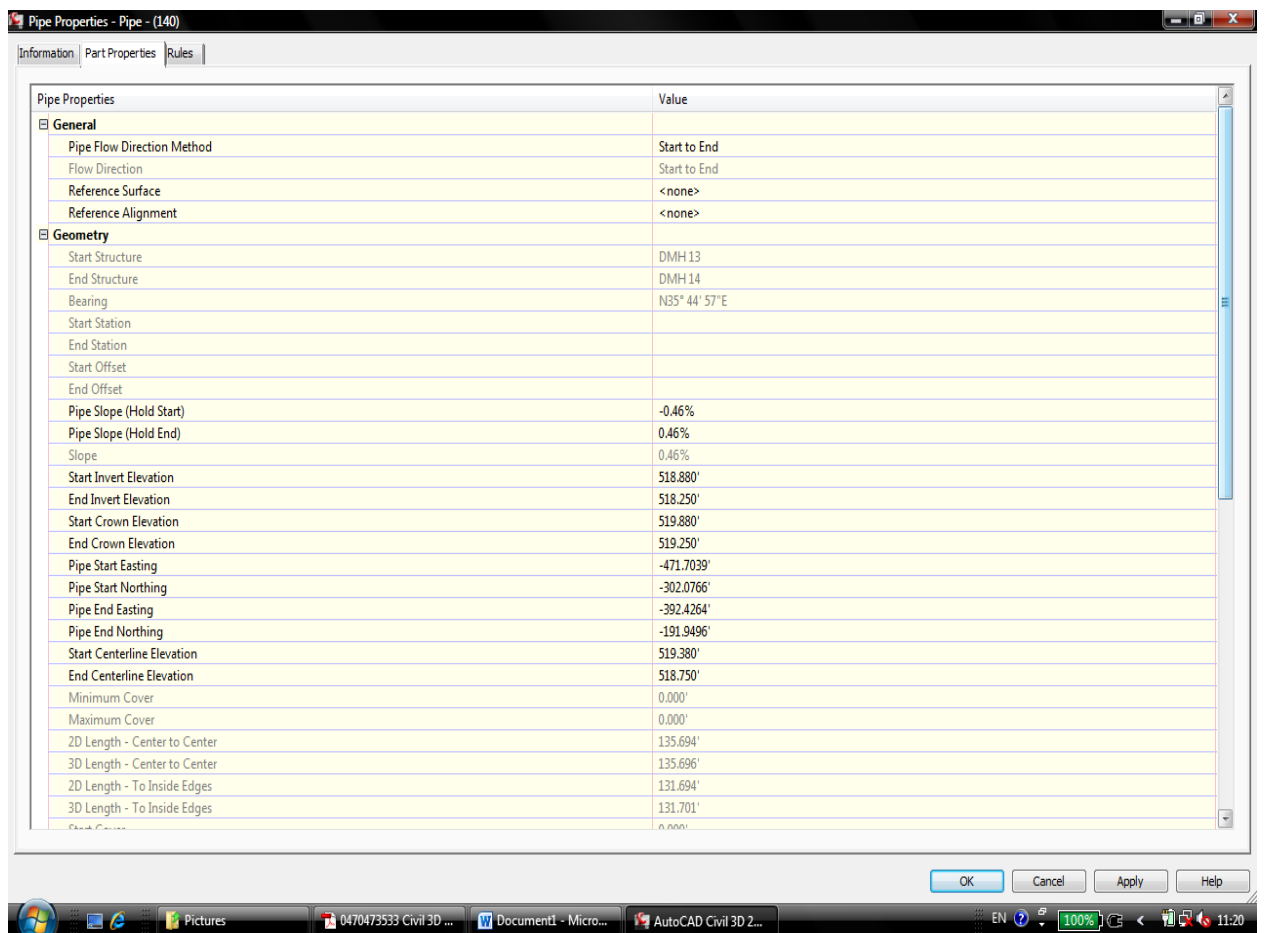**Figure 16: Civil 3D Pipe Model – Example of Drainage Manhole**

Figure 17: Civil 3D Pipe Model – Pipe Properties

➢ **Sewage system/Electrical Line/Telephone Line/Gas Line:** Other piping systems and connection parts could be modeled in a similar way. By creating different pipe networks for each one of the piping system, the modeling work of pipe and ducts for different uses would not interrupt each other, which would make the model's work become less confusing and more organized. Like Figure 18 shows below, different piping system can be marked as different colors, yellow is for gas line, blue is for drainage pipe and purple is for electrical line. This feature would certainly help the users of this model to get a quick general idea of how the site condition really is.
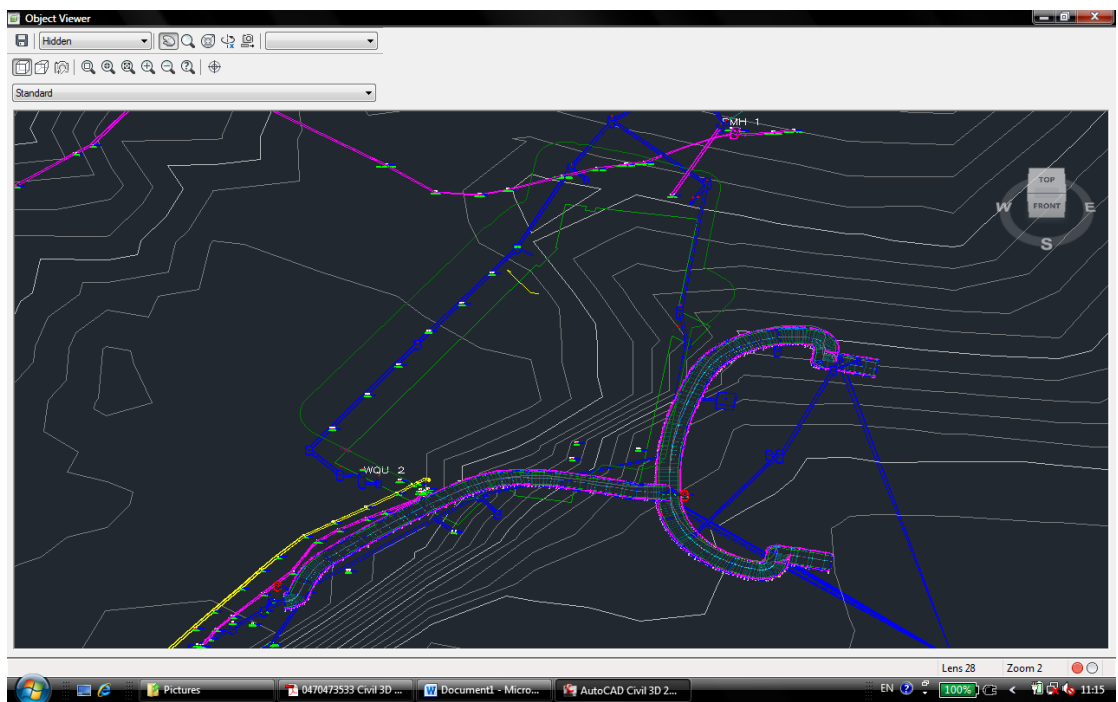
Figure 18: Overall 3D Underground Utilities

4.4.3 Excavation

After defining the entire utility situation, the second stage is to develop a building horizontal pad to show the elevation for excavation so that the user would know if the

excavation would disturb any existing pipe or connection structures. The goal in this stage is to provide 3 different phases of the construction:

➢ Preconstruction phase: the first one, I call it "Preconstruction phase", the model would show the original site condition before any excavation work takes place, which involves the basic up and down surface, the existing MEP system, and two major existing corridors along the excavation (Figure 19); This model, could be made to show the basic surface terrain with a certain depth, and all the contour lines on site carries its corresponding elevation, which is very suitable for developing an excavation in the next step.
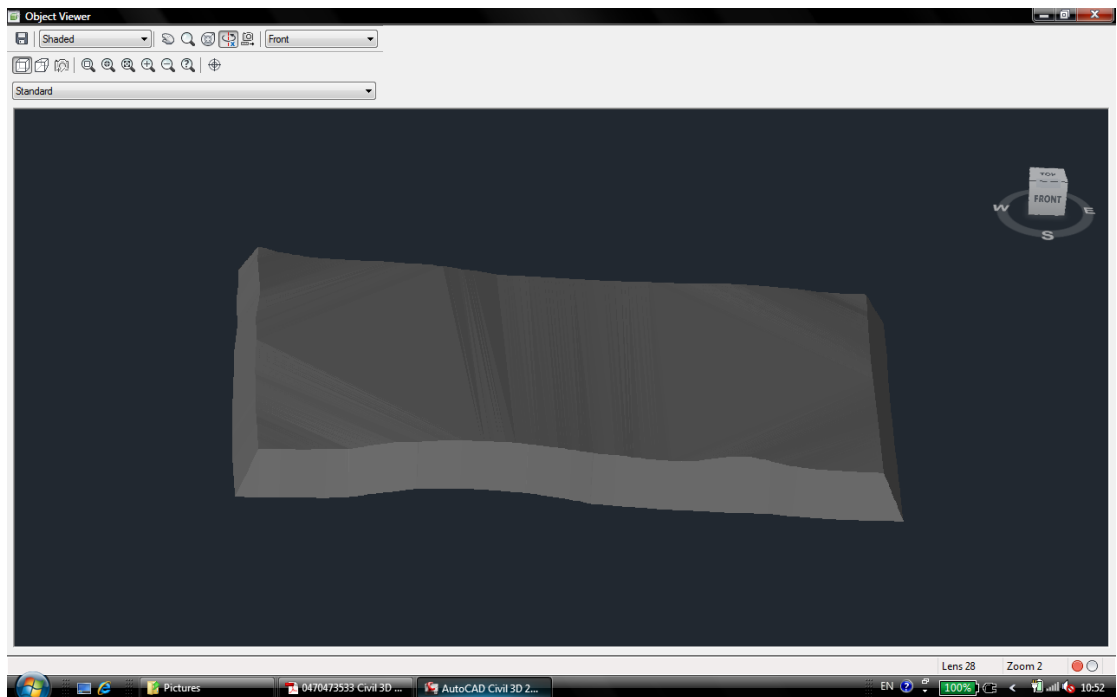
Figure 19: "Preconstruction Phase" – Civil 3D Terrain Model

➢ Excavation Phase: the second phase was to show the conditions for the excavation. In Civil 3D, one can use either an exist grading group or creating their own, in this case, we created a new grading group, which was defined as cut to the existing surface, excavation slope is 0.7:1, and use the average slope

as the interior corner overlap. Also created is a boundary around the grading, so that the whole excavation would appear at a lower elevation (500 feet in this case) as it shows in Figure 20 & 21.
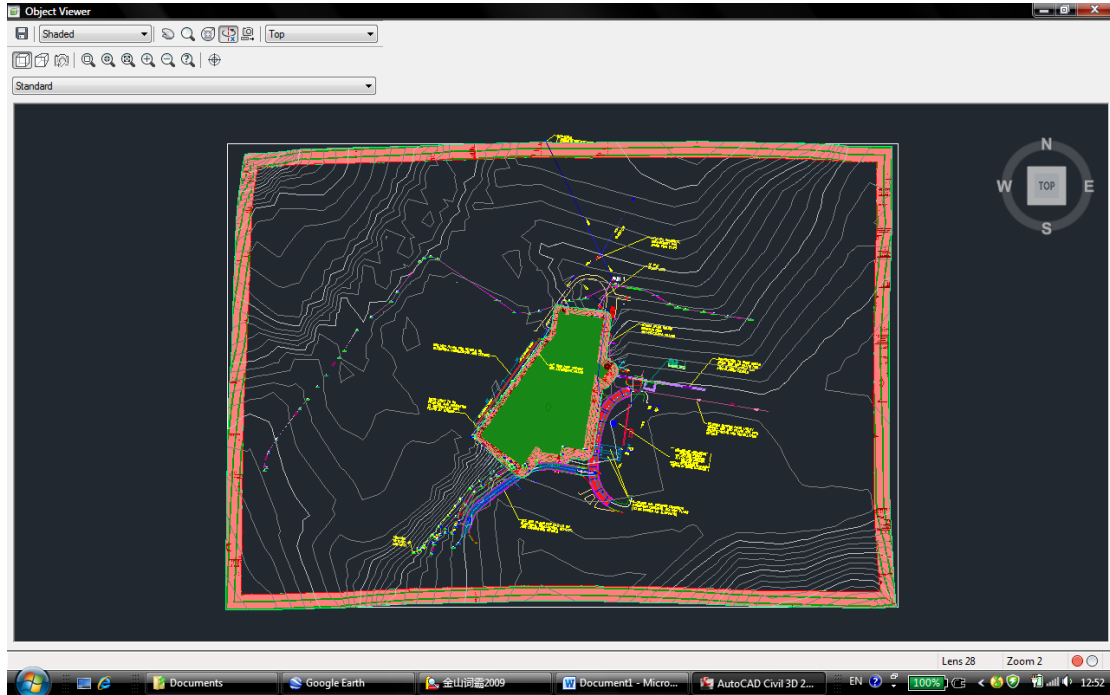

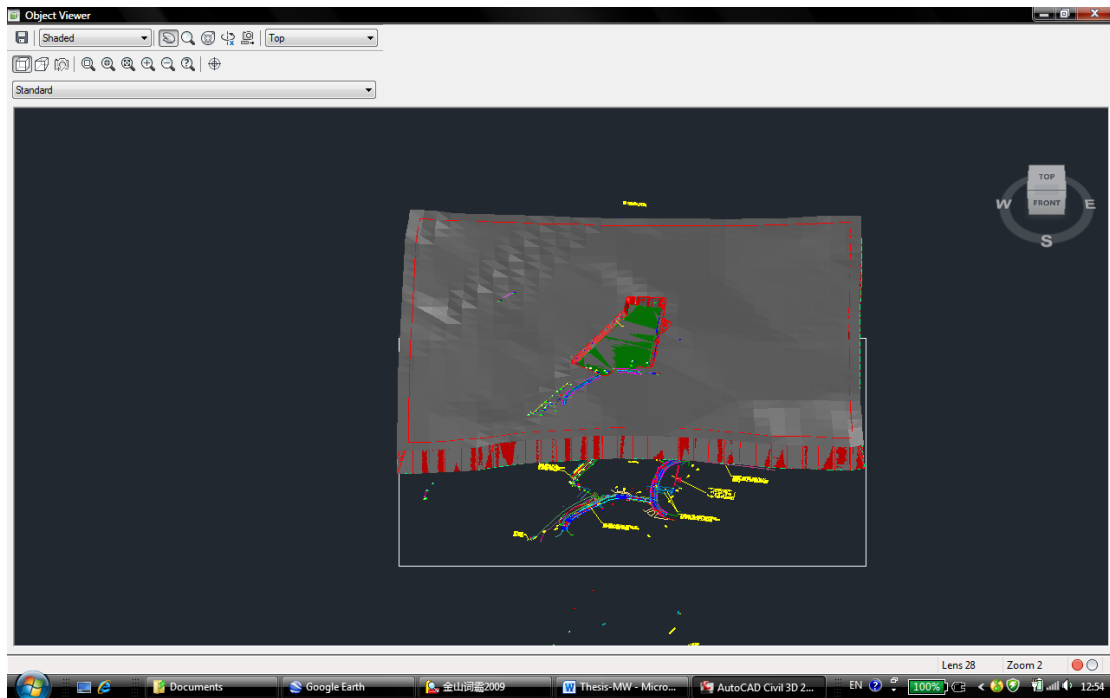**Figure 20: "Excavation Phase" – Civil 3D Site Model**

Figure 21: "Excavation Phase" – Civil 3D Site Model, Shaded

After the building pad was made, AutoCAD Civil 3D has the functionality to automatically calculate the volume of excavation in cubic yards of soil cut or fill needed for the excavation on site. Depending on the set grading this volume varies. In this case, the cut volume is 62866.16 Cu. Yd (Figure 22). Comparing this volume to the data that provided from WPI news on the web site, the calculation result is reliable. *"Excavation started in June, and approximately 60,000 cubic yards of soil were removed from the side of the hill overlooking Alumni Field"* (WPI, 2010).

Figure 22: Grading Volume Calculation Result

This calculation allows the construction engineer to plan the soil movements and storage on the site as well as truck access, combining its use with a site picture from the Google Earth.

In this case, according to the related report, half of these soils were transported to the following three locations: *"Gateway Park to cap a site at 10 Salisbury St; the town of Paxton for its renovation of the municipal recreation fields; and St. Peter Marian Junior-Senior High School in Worcester for its recreation field renovation project (WPI, 2010)."* The rest of the soil was storage on site for future excavation backfilling.

➢ Building on Site Phase: The last phase shows how the site would look like with the completed building sitting on it. This approach would combine the building design data together with the civil engineering design data, which would play a significant role in coordination between the architects and civil engineers. In this case, there is a 3D structural REVIT model and a just created Civil 3D site model, the key point is to understand how these two software interoperate with each other, and how to link the building model to the exact location in the site model. Basically, there are two methods to link the site model with the structural model. The first one is to export the building model as an *.adsk file from the Revit Architecture file, and then bring it to AutoCAD Civil 3D, this process will create a report of basic building information as well (Figure 11). Usually, this process would need that the two separate models were previously set up to the same geographic orientation, either true north or project north. However, in this case, the building model was set up to project north (Site model towards project north), and the central file cannot be changed in Revit without permission which in this case was created by the building designer. So that when you incorporate the two

models together, the building seems to have the right elevation, but the wrong orientation on site. In Civil 3D, since the two models both carry too much data and details, it is not easy to either move or rotate the building to fit in the excavation hole on the site model.

Thus, Navisworks® was considered. Navisworks®, as defined by Autodesk®, "is a software product that helps architecture, engineering and construction professionals gain control over project outcomes." It has powerful functionalities in integrating, sharing and reviewing 3D models and multi-formatting data with all different users involved in the same project.

In Navisworks®, the two models could be merged, and either one of them could be easily moved and rotated by defining the X, Y, Z and rotation angle, which is relatively accurate comparing to manually modified. As Figure 23 shows, after adjusted, the building model could perfectly match the excavation of the site.
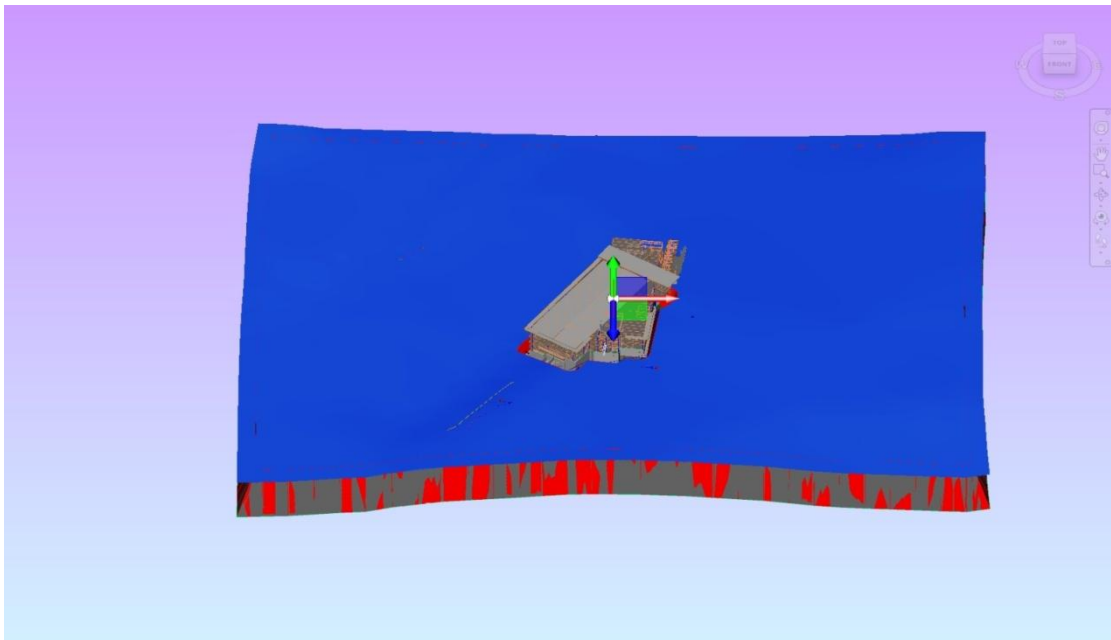

Figure 23: Site-linked BIM Model in Navisworks

By taking a closer look, we could find that the pipes running around the excavation and connected with the building at some point, which is what we proposed to have by creating a site-linked BIM model (Figure 24). Having this site-linked 3D model, we can run the functionalities of "Interference Check" in either Navisworks or Civil 3D, this process would makes sure there is no collision and interference among different pipes, checking the relationship between the excavation and the piping systems around the proposed building. By using this functionality, the engineer and construction team could decide what exactly the excavation would require and which area may need special attention and where shoring would be placed to support the construction and reduce its impact as much as possible (Christ, 2008).
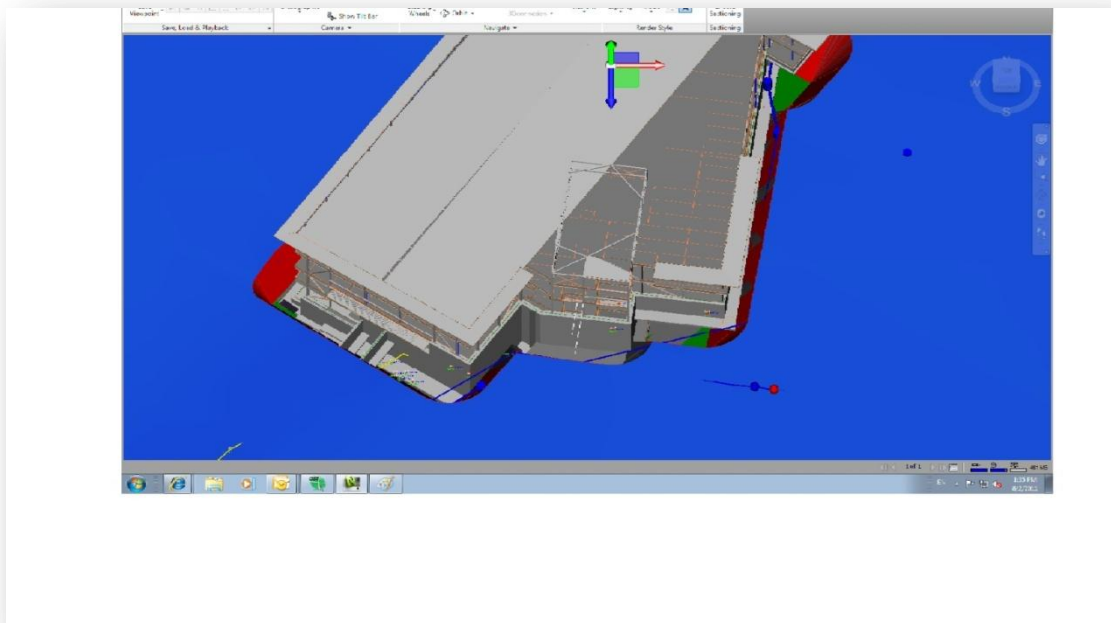

Figure 24: Closer shot of the Site-linked BIM Model in Navisworks

4.5 Additional Findings — BIM for Landscape

Create a site model would not only benefits the Civil Engineers and Construction

team, the landscape architects could also take advantage of using a well-defined site model. Although in this case, this information was not included in the model, s some features that would benefit the landscape designers were researched through browsing websites — both Autodesk and Bentley have already extended their market by delivering the BIM solution in landscape area, especially for the projects that involve a larger degree of site design. Many Software products including Revit Architecture and AutoCAD Civil 3D have powerful functionalities in providing a series of landscape tools such as corridors, curbs, plants, parking spaces, bollards and so on.

In AutoCAD Civil 3D, one can create his/her own landscape database which would make the design of planting much easier. Within the database, every single detail can be stored according to the user's wish; the plant can be defined as different width and height for automatic placing and spacing. Also, like any other BIM software, a schedule table could be created directly for review either as in Excel or other spread sheeting program (Landscape for AutoCAD, 2011).

The 3D landscape model, if finished, would help the landscape architects to optimize their design. For new buildings, it would help them understand the entire ecosystem around the building, get general ideas regarding to land use information and environmental constraints, which would play a significant role in the stage of conceptual design, so that they would have a better comprehension of different impact that comes with various alternatives.

And for renovation building, this model would also be valuable to determine how the construction would impact on the existing environment around the building, for example, during some sort of heavy site work, which plants need to be protected, which one need to be demolished and replaced, this would, to some degree, help some

large project to achieve the LEED requirement.

5. Conclusions — What BIM brought us on site?

The objectives of this report are to investigate feasible methods to create a site-linked BIM model, and to discuss the benefits and limitations of bringing BIM concept to the site conditions. Four different methods by using different software developed by Autodesk, Bentley and Graphisoft were discussed in the previous sections, Method 2, which is using Revit Architecture and AutoCAD Civil 3D was used and testified as a feasible procedure through the case study.

The broad pros and cons of BIM in the AEC industry have been substantially discussed in this report; by bringing the concept of BIM to site condition, the building is no longer treated in isolation of its surround site but incorporates extremely helpful short-term and long-term information for the owner, designer, and builder regarding site topography, landscaping, access roads, ground conditions and the location of site utilities. The following conclusions specifically focus on the benefits and limitations when it comes to the topic of site-building integrated model.

5.1 Benefits

➢ Better visualization and documentation

Every BIM software, either Revit or AutoCAD Civil 3D provides the users with a much better visualization comparing to the old fashioned 2D design software. Autodesk describe AutoCAD Civil 3D as *"an effective BIM solution for civil engineering design and documentation by providing a better 3D visualization and possible design alternatives (Autodesk, 2011)."* With the help of 3D view, it is easy to get a general idea of how the site conditions surrounding the proposed

building look like prior after and during construction, what impact the new construction would have on the existing environment. The new released Civil3D also includes the enhanced alignment layout and tools that make the sharing of design standards easier across organizations. The corridor enhancements include tools that streamline corridor editing by providing for interaction in plan, profile and section view simultaneously. The created 3D site model can either be published to Google Earth or be exported as DWG files to help communicate design intent to nontechnical audiences. In addition, since 2010, the "Civil Visualization Extension" is available for the subscription of Autodesk to download, which provides a process to take Civil 3D surface and corridors, easily incorporate them in 3Ds Max design, so that we can create a compelling visualizations.

➢ Single and integrated information resource

A site linked BIM model integrates information from different project parties together as a single information resource. In the case study of WPI new sports and recreation center, before the site-linked BIM model was built, the project has many pieces of information resource, the paper drawing and structural building model from Cannon Design, Inc., the as-built CAD drawing and a building model developed by Gilbane, Inc., the geotechnical report prepared by Haley & Aldrich, Inc. As the figure shows, there are pieces of information everywhere, however, by bring in the integrated BIM model, all of these information could be carried by one single 3D site-linked building Model.

This single integrated resource could be shared by all the users, which would save a lot of paper work, as well as improve the coordination and cooperation within the project team.

➢ Time Saving Utility Design

AutoCAD Civil 3D provides the powerful functionality to create, swap or move pipe networks in the plan view, one can easily define his pipe network to contain pipes only, structures only or like in this case, both pipes and structures according to the real site condition. It has a full list of multiple pipes and structures ready to use, the size and style can always be redefined after the network has been set up. For some special parts that not exists in the list, the user can always create a part list comprised of only the part catalog items and save it for future use. Not like in the 2D paper work, by using the "select similar" tool, all the pipe with the same properties can be changed at only one time, which would save a lot of time for engineers, and also reduce the potential mistakes that may caused by ignorance.

➢ Interference checking, less collisions

Some BIM software carries this functional tool: interference checking. By having the well-defined site model with existing underground condition and the excavation pad on site, this tool would simply allow the user to identify the following two situations and would play a significant role in reducing possible collisions during future constructions.

1. If there is any interference between different pipes or among different piping network.

2. If there is any collision between the proposed excavation and the existing underground condition.

➢ Energy Saving Design – BIM for Sustainable Design

BIM goes beyond the building helps the civil engineer to create more sustainable land development, transportation and environmental projects. Some civil engineering BIM software allows the user to analyze the storm water runoff to design solutions, for example, AutoCAD Civil 3D, which would limit the disruption of natural hydrology. For landscape architects, bringing BIM to landscape would make the site design much easier, through taking advantage of the 3D model, they could maximize the possible open space and minimize site disturbance during construction (Autodesk, 2009).

5.2   Limitations

5.2.1   Technology Support

➢ More Software involved: To create a 3D building model, usually, just single software like Autodesk Revit Architecture/Structure or Bentley Architecture could do that. However, when it comes to the idea of BIM on site, more software need to be involved to create a site-linked building model that carried all the necessary database information. Like what has been discussed above in the case study, the site model and the building model may be created by two different software, the interoperability between those software may become a big concern, how they interact with each other, will there be any missing and overlap when importing one model into another software. For the orientation issue, the solutions this paper provided are to import and export the model as corresponding format and settle up both the site model and the building model by using the same orientation; it could also be solved by using a integration software like Navisworks and Bentley Navigator. On the other hand, missing and overlapping problem could be another issue, this would require the designers and engineers to

plan a clear allocation of model work before it actually start.

➢ Higher Requirement of Documented Software Knowledge: According to this researcher's own experience of using BIM software to create the site model, it seems like creating a site model may require more technology support comparing to modeling the building itself. It is not easy to start to use software like AutoCAD Civil 3D if one is new to the software, although in the real construction area, most civil engineering and landscape architect may have plenty of experience in using AutoCAD to create 2D DWG site drawings, it is still not very straight forward to start things like grading, corridors and pipe network in Civil 3D. To make sure everything is moving smoothly in creating a site model, the modeler should at least meet the following requirements:

- o Have the basic knowledge of Site Design and Site MEP System

- o Familiar with the other BIM design software like Autodesk Revit Architecture, AutoCAD

- o Familiar with the site condition and environment around the proposed building

- o Have access to the tutorial and other learning materials of the software that being used to create the site model, have a general idea of what are the basic elements that need to be defined first and how some basic functional tools works, what does the software have and what need to be defined by user himself as a family and so on.

5.2.2 BIM in Real World — Coordination Problems

➢ Coordination within the building model:

Another possible drawback is, in the real world, especially for a large complicated project, the whole BIM model would not be designed by

the same person, usually, the BIM department would have several groups, each of them would be responsible for one section of the model, for example, there might be BIM model for shell, interior, mechanical and plumbing separately instead of an integrated building model, and then they may have an overall site model. Although theoretically, those models can be linked together as an integral model, however, in the real world, the coorination of software and people interaction might be very frustrating. Since the work was done by a very different group, if they are not using the same coordination, for example, the shell model may have elevation slightly different from the interior finish model, which is hard to find out in separate BIM model, however, when link the two files together, it is probably a mess since they do not match together. Another issue related to this situation is that there might be some overlapping model work in different group which makes the allocation of model work very important.

➢ Coordination between the site model and the building model:

Another common issue arises when trying to link the building model and the site model together, which was experienced in the process of assembling the case study. Since the site model is created by the civil engineer, and the building model is created by the architect or structural engineer, and they do not usually use the same coordination, then when one try to link the building with the site, the two models are not necessarily smart enough to know where each other belongs, and they seem to appear as two separate models at different location in the same file. To avoid this situation, it requires good communication

between the architect and the engineer, so they can set up their model at the same coordination, either as project north or true north. In addition, they should have the same project information resources, so that their design would be developed based on the same standard, imagine if the building footprint matches perfectly with the excavation hole in the site model, the utility line within the building can exactly connect with the existing pipe surrounding the building, that would save a lot of time and human resources to further adjusting the model.

6.Further Work

This research proposed several feasible methods to accomplish the site-building model integration by using different software; the case study recommends technology support of using AutoCAD Civil 3D and Revit Architecture to create a site-linked BIM model. Utilities, corridors, trench, grading, excavation has been modeled. Advantages and limitations are discussed by analyzing the process and result of the case study.

Based on this research, more work could be done in the future to make it more efficient. Future work can be expanded in three aspects.

6.1   Future Research Work

First, some further theoretical study could be done around the site model itself, how to create a more completed model, how many details should the model involve, who should be responsible for the model, the coordination between the building modeler and the site modeler and so on.

6.2   Future Application Work

Secondly, from the technology aspect, one software technology solution was explored in more detail using Civil 3D to create a site-linked model, however, Bentely products seems to be a very promising and seemingly more suitable software according to their product descriptive literature. It is therefore recommended to explore this technical software solution. It would be valuable to continue a research on how to use Bentley products to create this site-linked model, compare the method with what this report proposes and then provide the best method for the whole AEC area.

6.3   From One Building & One Site to 3D Campus Maps

Another research direction is to involve more buildings on site. This research provided the solution concerning only one building and one site. Future study could focus on how to create a Mini GIS, like what was discussed in the background section of this report, which is one site with several buildings sitting on it. Take WPI as an example, we can put all the existing 3D building models in the same campus, like Kaven Hall, Washburn. This research could be very useful for campus design and operations. Also the whole digital campus model could be used to facilitate design collaboration, support construction delivery, and leverage facility information for operations and maintenance.

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Appendix 1 — Process of Using ArchiCAD to Create a Topographic Surface (Graphisoft, 2011)

ArchiCAD- Step by Step to create a toposurface, the tutorial published by Graphisoft was used as reference.

One can either start out with a Scanned Image or in the form of a civil engineer's DWG files.

Start out with a scanned image.

The scanned image is not like a CAD drawings which is defined by precise lines that has an exact start point and ending point. From what I've found, under this situation, the scanned image can be imported as the following format: pict, bmp, jpg and tif.

This method cannot be 100% accurate because after the scan is scaled properly, the contour lines will be created by "trace" over the scanned line by using tools in ArchiCAD.

Starting out with a DWG file

- First of all, merge the DWG directly into ArchiCAD. And then, similar to the procedures in REVIT, manage the layer so that the unnecessary information for topography would be hiddend like C-PKNG or L-PLNT.

Common issues: the contour lines might be broken where the elevation of the line is marked— draw the mesh contours manually or redraw the contours using the spline tool and then using the magic wand with the mesh tool to trace the splines.

- Use the mesh tool to define the site boundaries and create the toposurface. After the top surface has been created, other functionalities can be applied too, like adding roads to the site or cut a hole on site as an excavation.

Appendix 2 — Case Study Procedures

Software used: AutoCAD Civil 3D 2011, Google Earth, Navisworks 2012

Software Tutorial: AutoCAD Civil 3D 2011 Tutorial (Autodesk, 2011)

Goal: Create a site model that carries all the useful as built information that the construction team may need

- **Create a Proposed Toposurface in AutoCAD Civil 3D**

   1. Import the Google Earth Picture into Civil 3D

       Open Google Earth, search the key word "Worcester Polytechnic Institute" and zoom in the site as tightly as possible since the accuracy of Google Earth is zoom-level dependent (Figure 25).
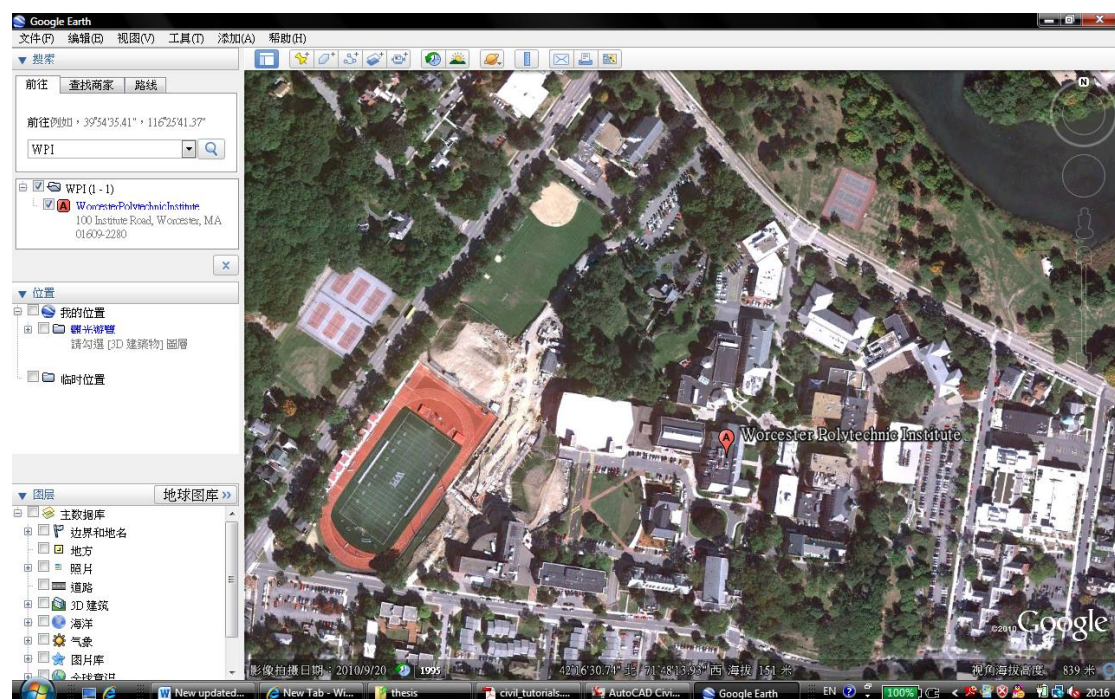
Figure 25: Google Earth Picture

       Keep the Google Earth open, and then open AutoCAD Civil 3D. Create a new drawing from the template imperial NCS Extended and saved it as a name of "WPI Rec Center .rvt".

From the main tool bar, File>Import>Import Google Earth Surface, since we need two surface to create a volumed proposed surface, we will need to import the Google Earth surface twice, and also import the Google Earth picture later as an reference. For this one, press enter, <0,0,0> as the insertion point, <0> as rotation angle (Figure 26).
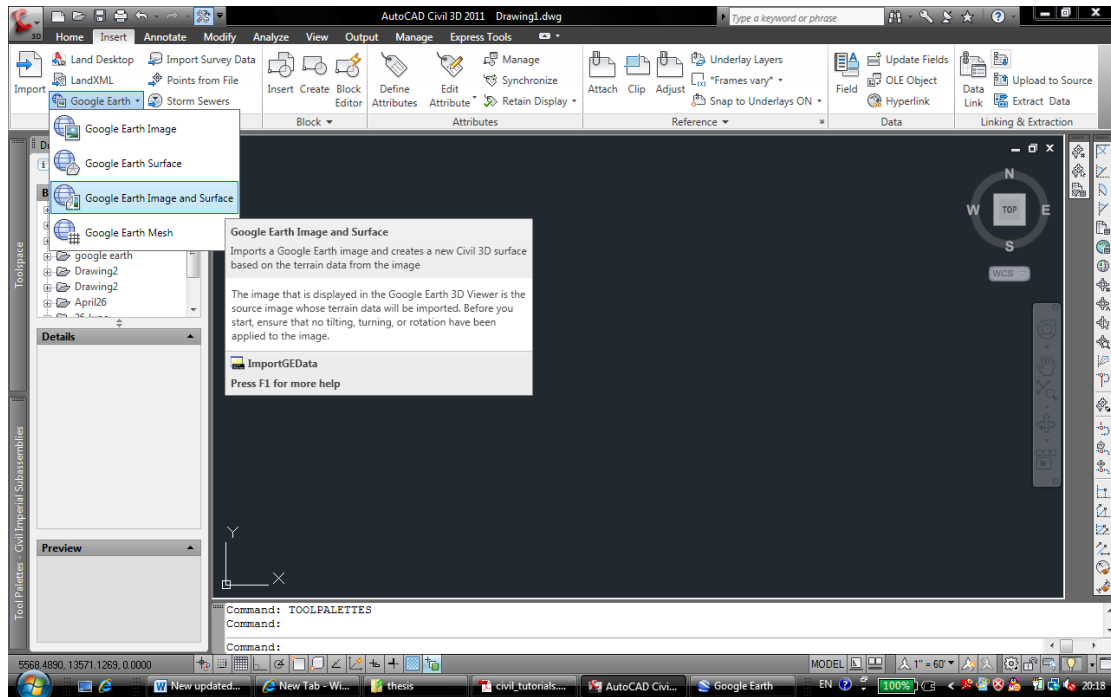
Figure 26: Import Google Earth Surface into Civil 3D
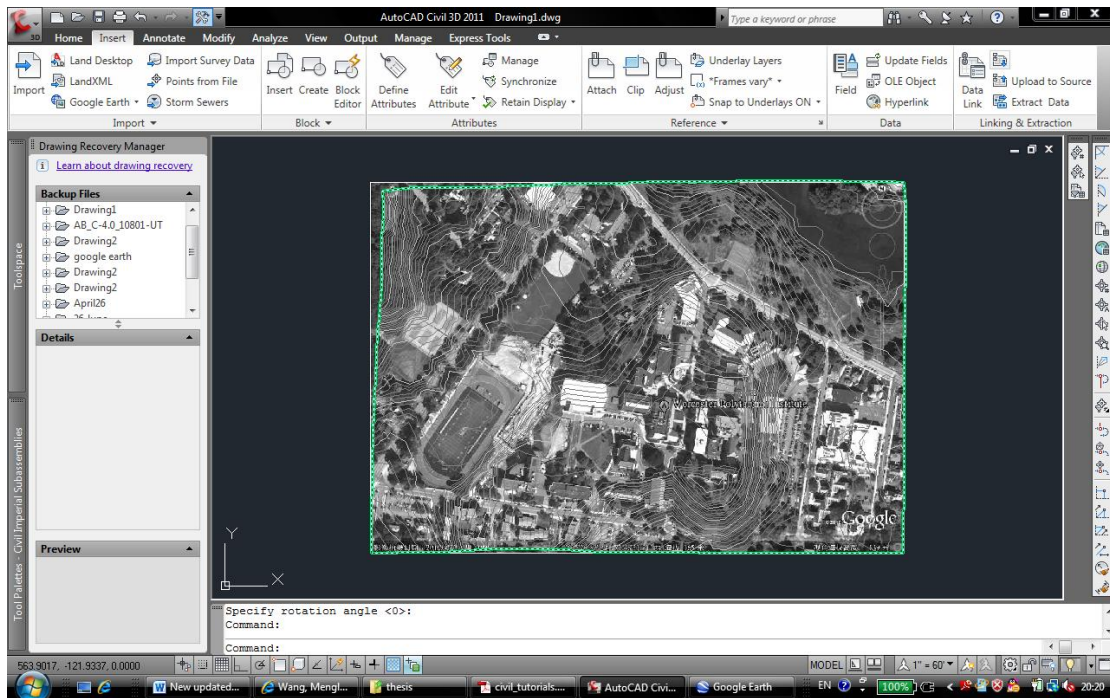
Figure 27: Bottom Surface

Since I would use this one as the base surface when I create the proposed site, I named it "Bottom Surface" (Figure 27), and there is no need to extract the countour line from the surface, but the feature line would be used for further grading, so I exposed the site and choose the outline of the site, click Home>Fiture line>create feature lines from objects, this process will change the polyline into feature line.

The surface carried the original elevation from Google Earth, now we need to lower it so that it can be used as bottom surface later. Select the surface, under Tin surface: Bottom Surface, choose Edit surface, in the drop down menu, click Raise/Lower Surface, input "-100", press enter, now the elevation of the whole surface was lowered.

Import the Surface from Google Earth Again, only this time import both the surface and the Google Earth Picture, keep its original elevation and name it "Top Surface".

Now that we have two separate surface, Civil 3D has the functionalities of creating a TIN Volume Surface. Home>Surface>Create Surface, in the popup window, Type: Tin volume surface, chage the name to "Proposed Site", select the bottom surface as base surface, the top surface as comparison surface, then hit OK (Figure 19).

- **Use AutoCAD Information in Civil 3D**

    Based on the materials on hand, first thing I did is to import the Auto CAD DWG. Drawing into AutoCAD Civil 3D. As noted above, now I have two separate DWG drawings, one is a proposed site of the whole WPI campus (Figure 19), the other is the flat 2D site drawing with the as built utility information(Figure 8). The first step is to combine these two separate drawing into a unit file, ideally, we would have all the utility information appear above the 3D toposurface from the front view, so that the (x,y) of each utility would be determined, and all that's left is to define the pipes with the given elevation.

    To combine these two drawings, just simply copy and paste would do it, the key is to make sure that the utilities can be put on the exact place above the terrain by defining the insert point (Figure 28).
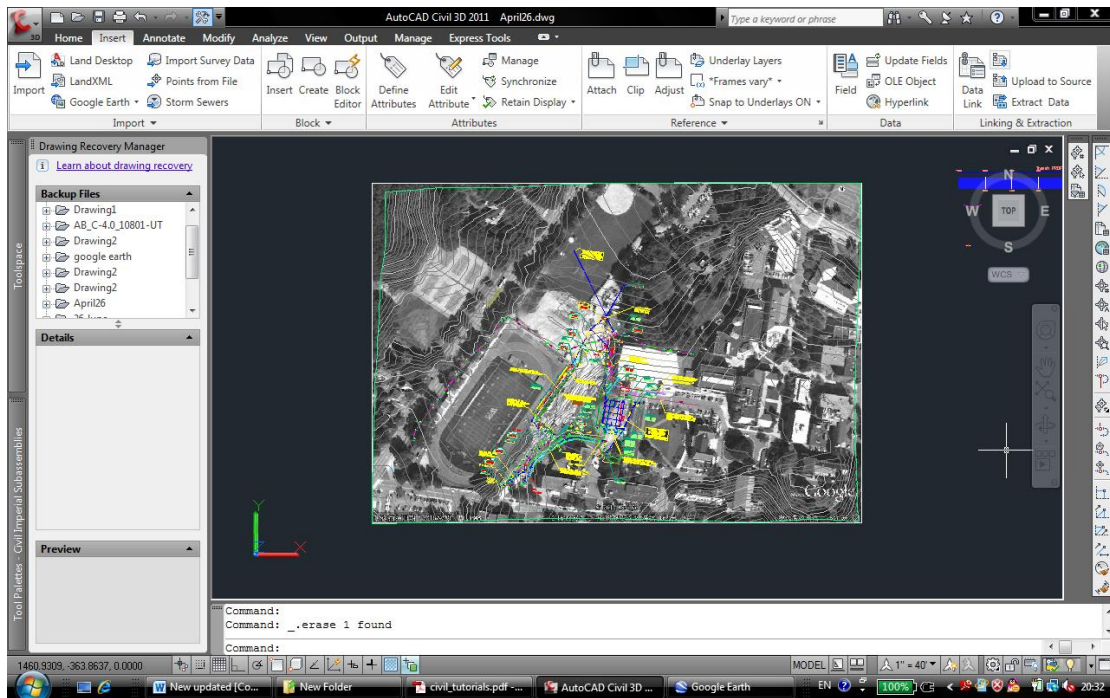
Figure 28: Bring CAD Information into Civil 3D

In Civil 3D, one can create the drainage pipe system, select the corresponding type, size and material of the pipe and the connection part, and then simply draw the pipe to cover the lines on the CAD drawing.

- **Create Excavation with a certain depth on Site**

  According to the WPI New Recreation Center Structural Precast Concrete Bid Package (Cannon, 2009), the lowest level of this proposed buildding is around 505, that is where the excavation would go.

  1. Whole Site Grading: Turn the building outline into feature line, name it "excavation outline", then use the grading tool to create an excavation. In this case, Home>Grading, in the drop down menu, select grading creation tools. The first step is to set a grading group. In the pop out window, select Site 1, then create a grading group, name it "Excavation", make sure the volume base surface is selected as proposed site, then hit ok. The grading group now is set up (Figure 29).
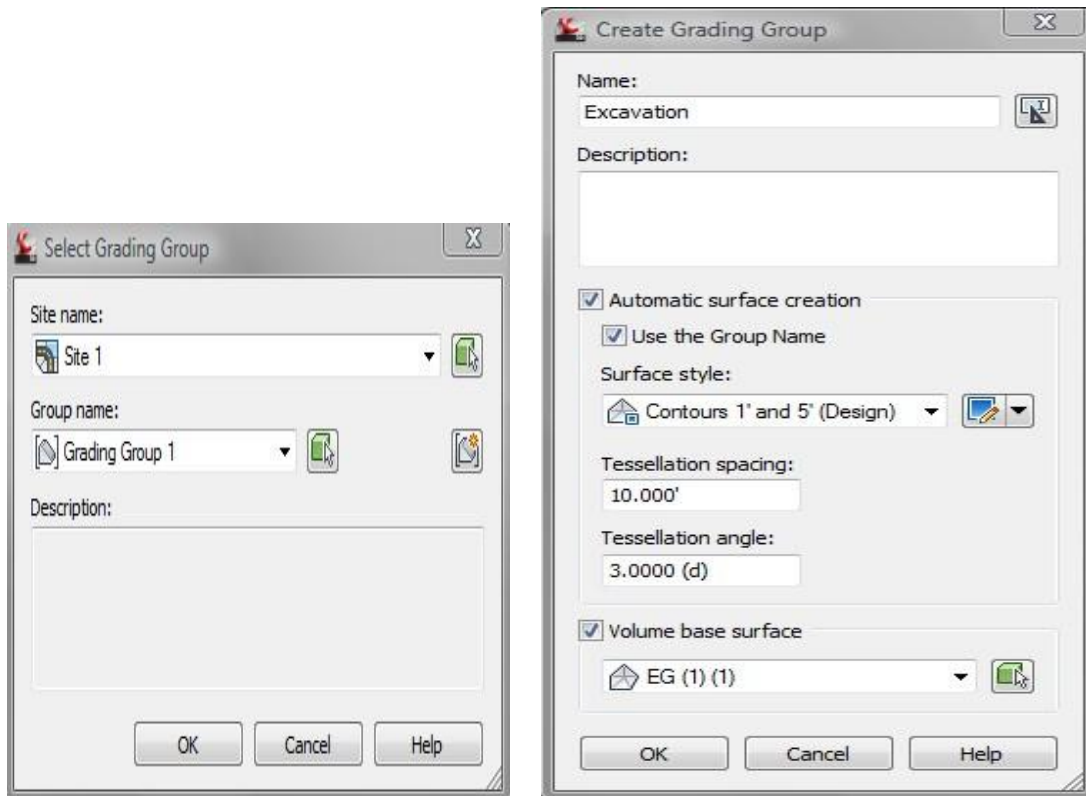
Figure 29: Creating Grading Group

Secondly, create new grading criteria. In this case, choose the grade to surface as grading method, define the cut and infill format, and value of grade as it shows in the picture below, hit OK (Figure 30).

Click the create grading button on the grading creation tools bar, select the excavation outline, then select the outer side as grading side, press enter 4 times. The whole Site grading is now completed (Figure 31 & 32).
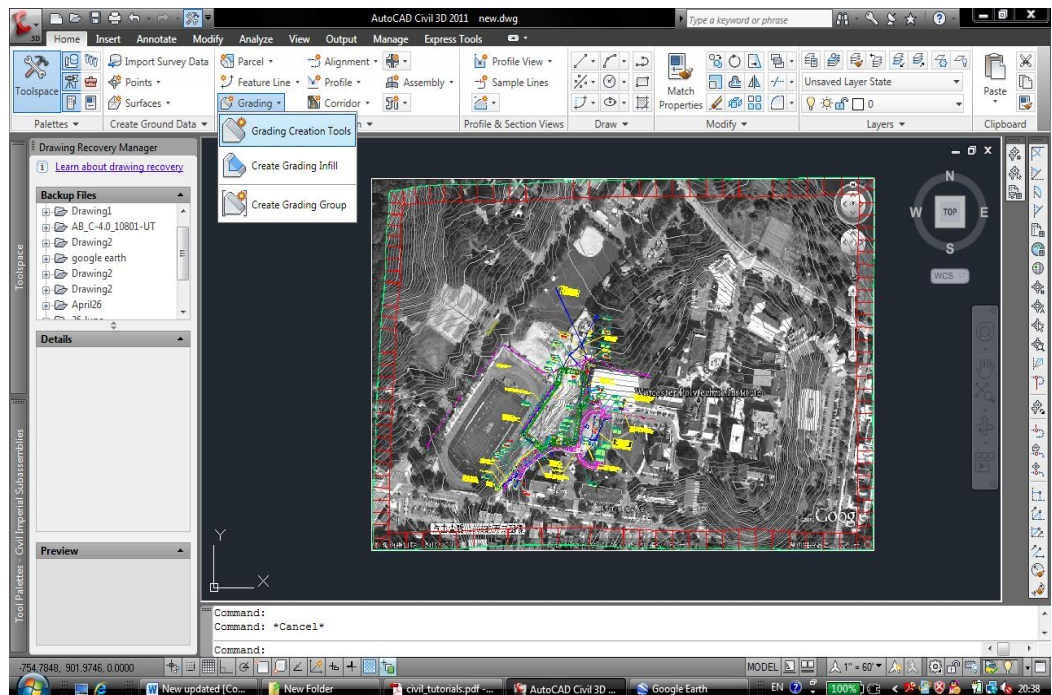
Figure 31: Whole Site Grading-1
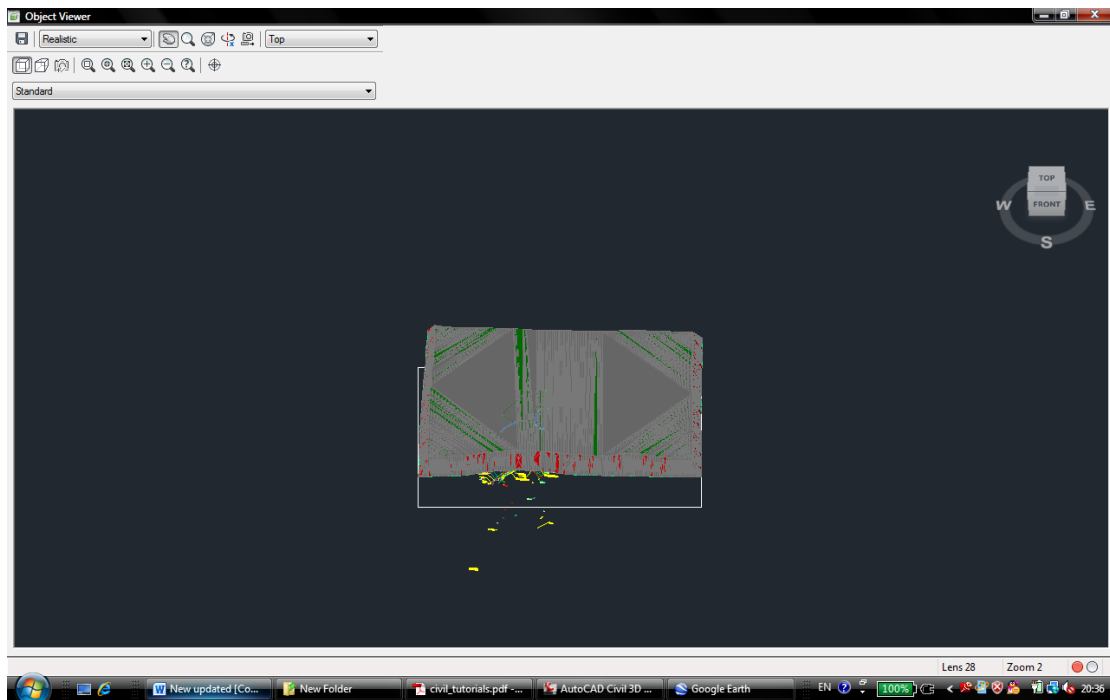
Figure 32: Whole Site Grading-2

2. Excavation Grading

Home Tab>Feature Line>Create Feature Line from stepped offsets

Offsets distance: 0.5

Select the outline of building outline, outer side, then hit ok.

Create a new grading group, name it "Excavation".

Define grading criteria as in Figure 33 below shows.

Create the grading using the same procedures as in step 1.

Figure 34 shows the completed work.
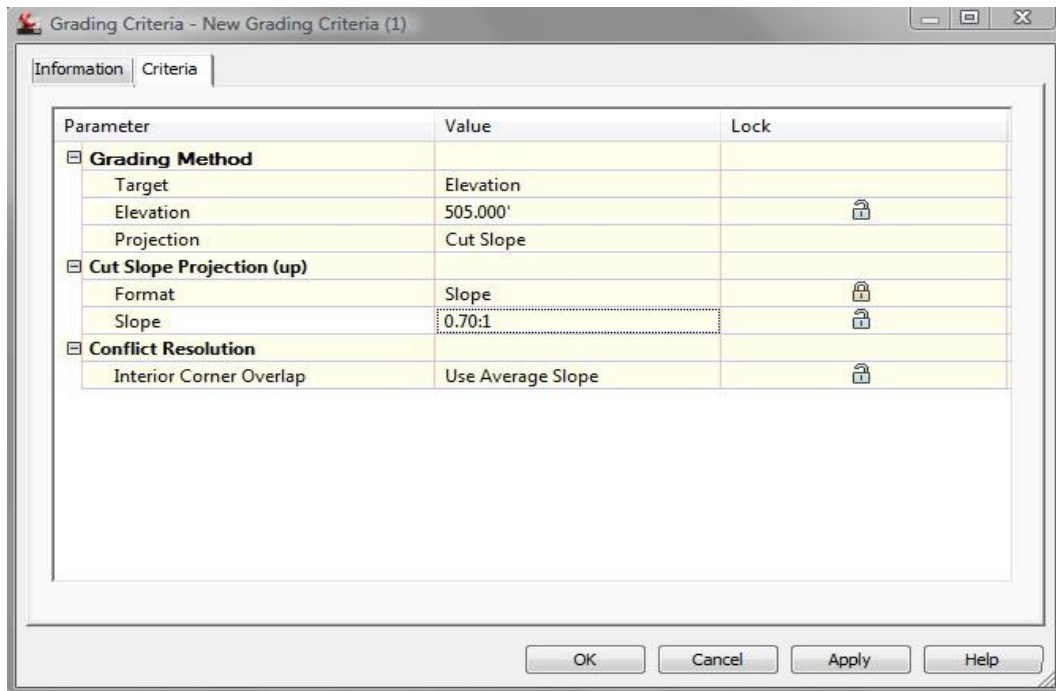
Figure 33: Grading Criteria--Whole Site
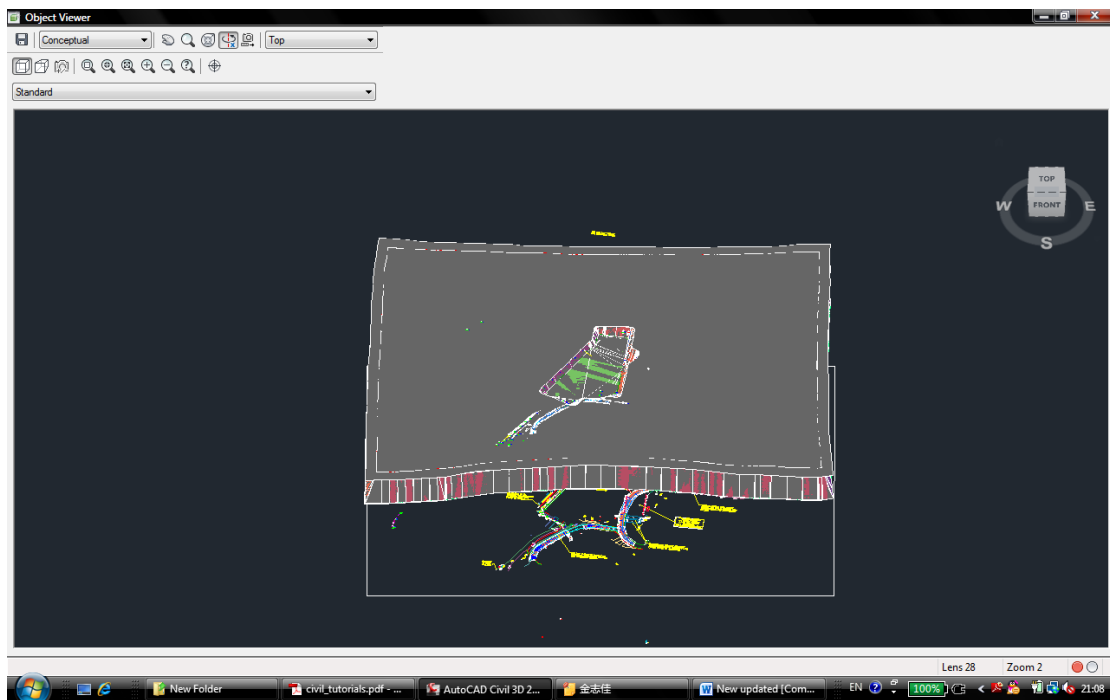
Figure 34: Grading—Excavation

● **Create Underground Utilities**

Use AutoCAD Civil 3D 2011 User's Guide page 1334-1335 as reference to

define the underground utilities for this case study.

Take Drainage piping system as example, other piping system including sewage, water line, gas line, electrical line, and telephone line would use the same procedures.

Home tab>Create Design Panel>Pipe network drop-down>Pipe network creations (Figure 35)

In the create network dialog box, enter the name "drainage pipe", other factors are defined as Figure 36 shows. Hit OK.

On the network layout tools toolbar, select 48-inch Cylindrical Structure and 12-inch HDPE pipe for the 12'' drainage pipe and connected manholes. And for those that are 8'' pipes, define them as 8-inch Ductile Iron Pipe.

Choose to draw both the pipes and structures.
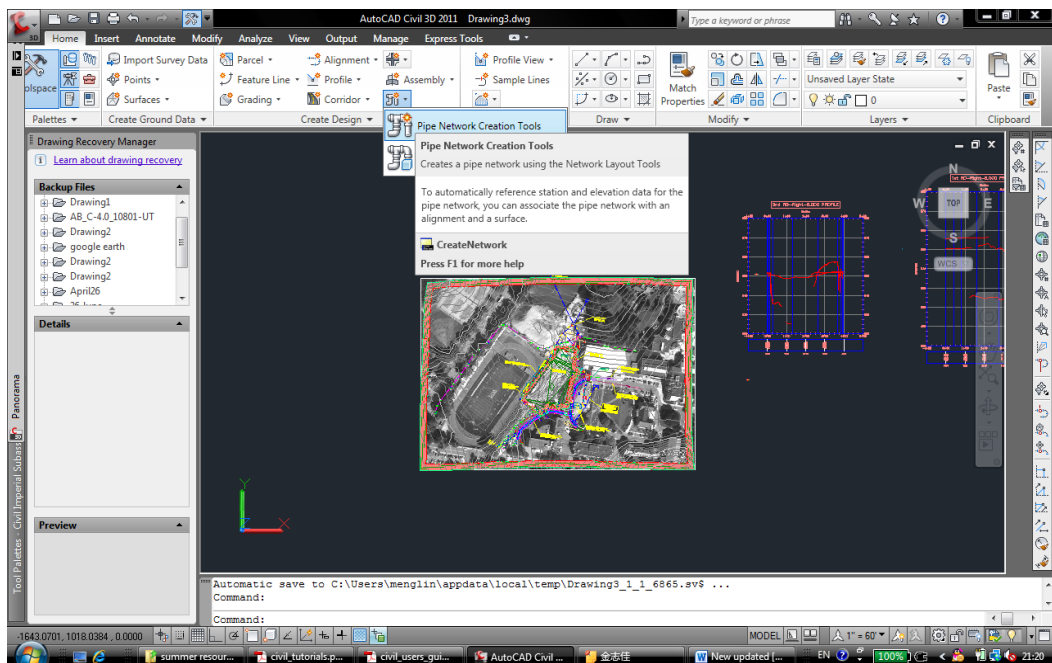
Figure 35: Create pipe network
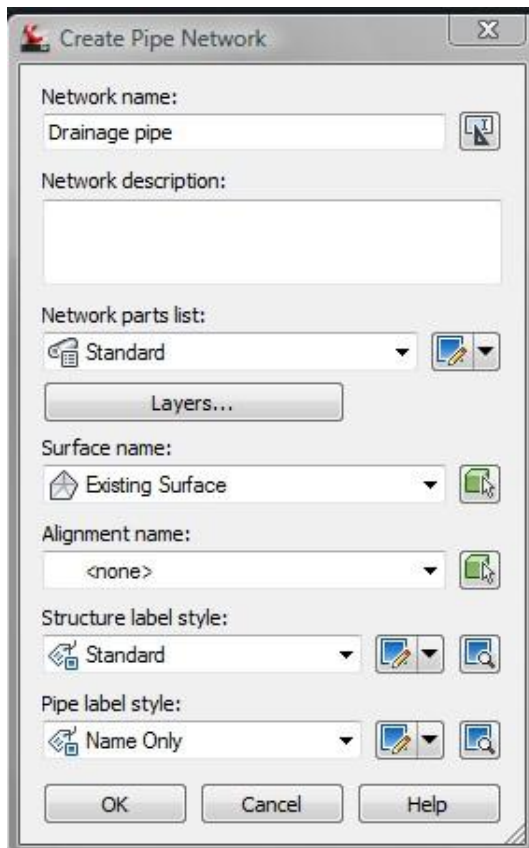
Figure 36: Create Drainage Pipe network

Then start to draw the pipe along the pipe line on the existing CAD drawing.

When finished, click the manhole, right click, and edit structure style.

In the structure style window, under the information tab, change the name to DMH

(Figure 37); under the plan tab, choose drainage manhole as block name, make sure

all the components are visible under view tab, hit apply, ok.
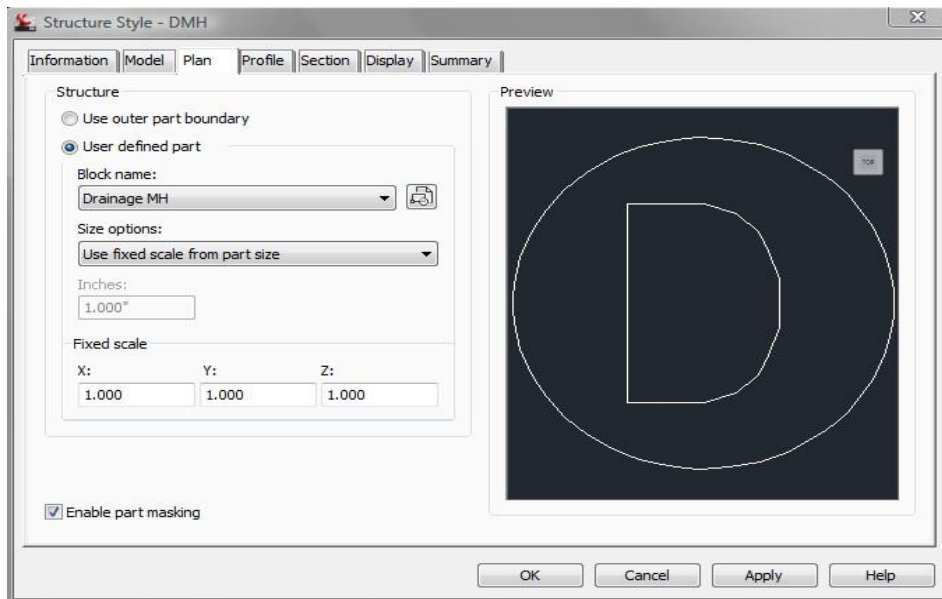
Then the pipe and structure model would appear like Figure 38, next step is to define the elevation of each element. Click on the DMH, right click, structure properties.
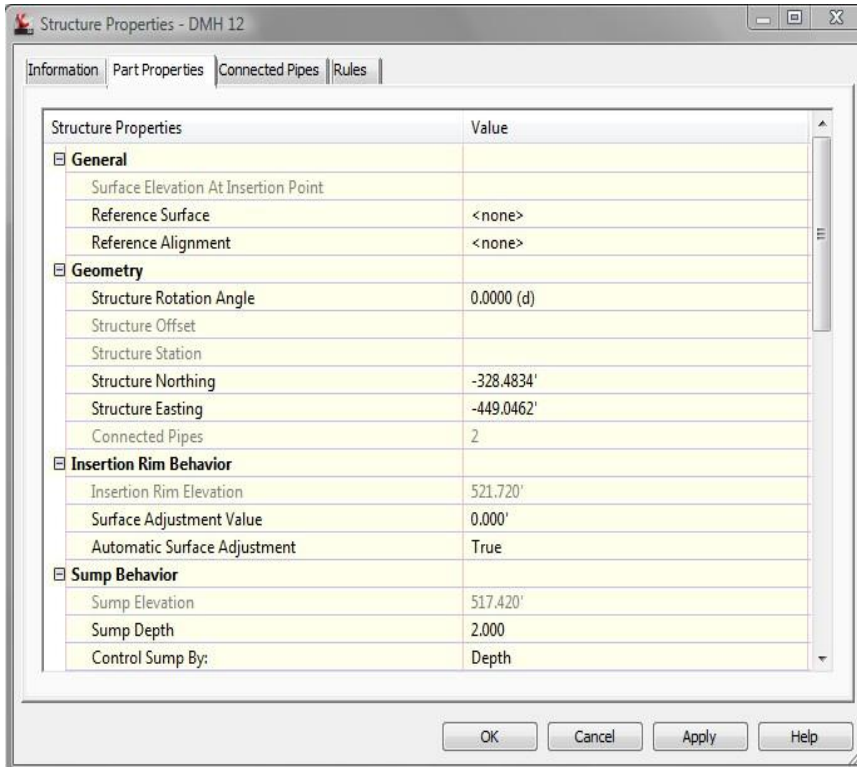
Figure 39: DMH 12 Structure Properties—1

For DMH 12, the rim elevation was defined as 521.72' (Figure 39). Also, define the two connected pipes as follows (Figure 40).
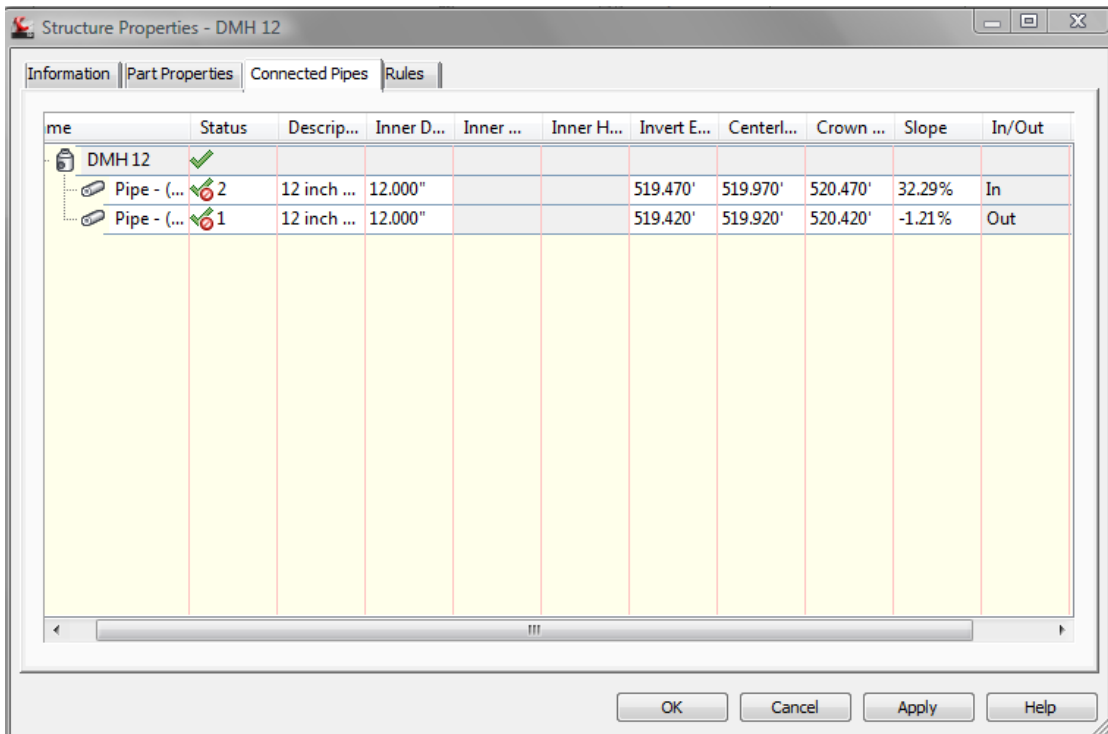
Figure 40: DMH 12 Structure Properties—2

Repeat the steps above to create the whole drainage system.

Use the same procedures to create different networks for sewage, gas, water, electrical

and telephone line (Figure 41).
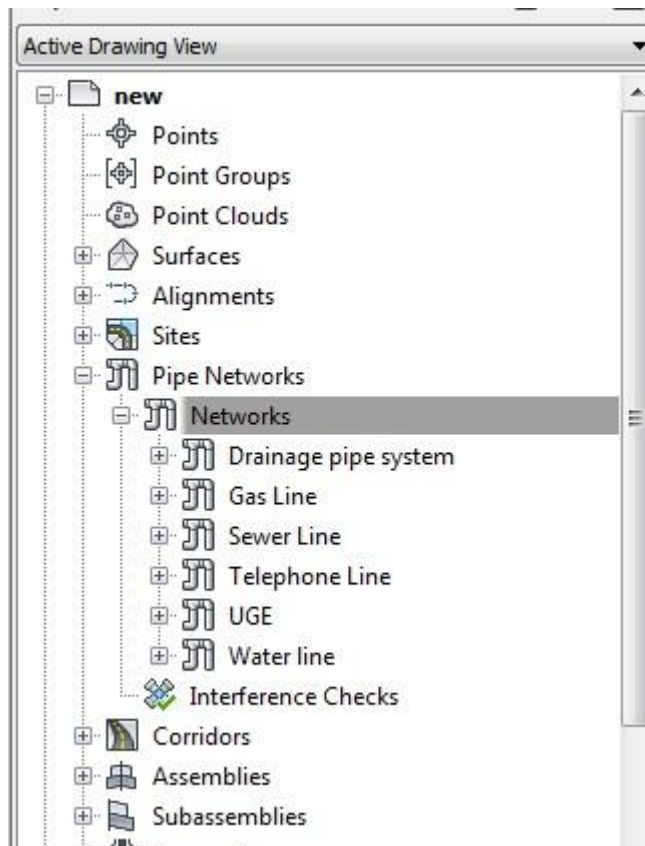
Figure 41: Whole Pipe Networks

- Link Site and Building Together

  Export Revit file as DWF file format.

  Home>Export>DWF/DWFS (Figure 42)

  Define the project information if needed as Figure 43 shows.
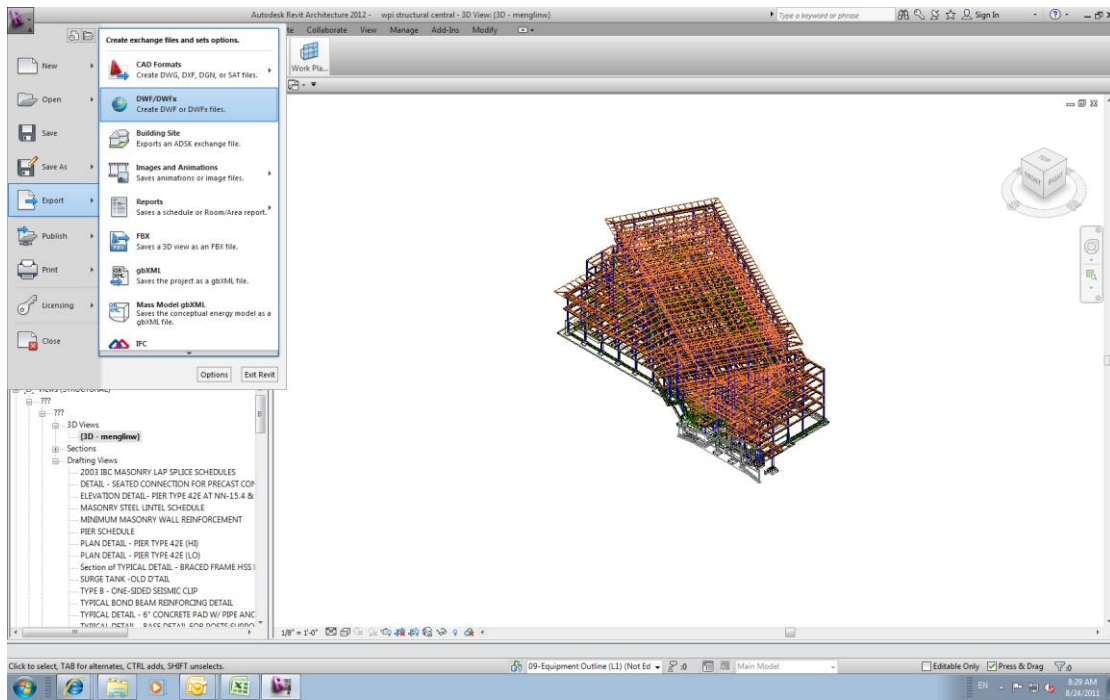
  Click OK.

  Rename it "building.dwf".

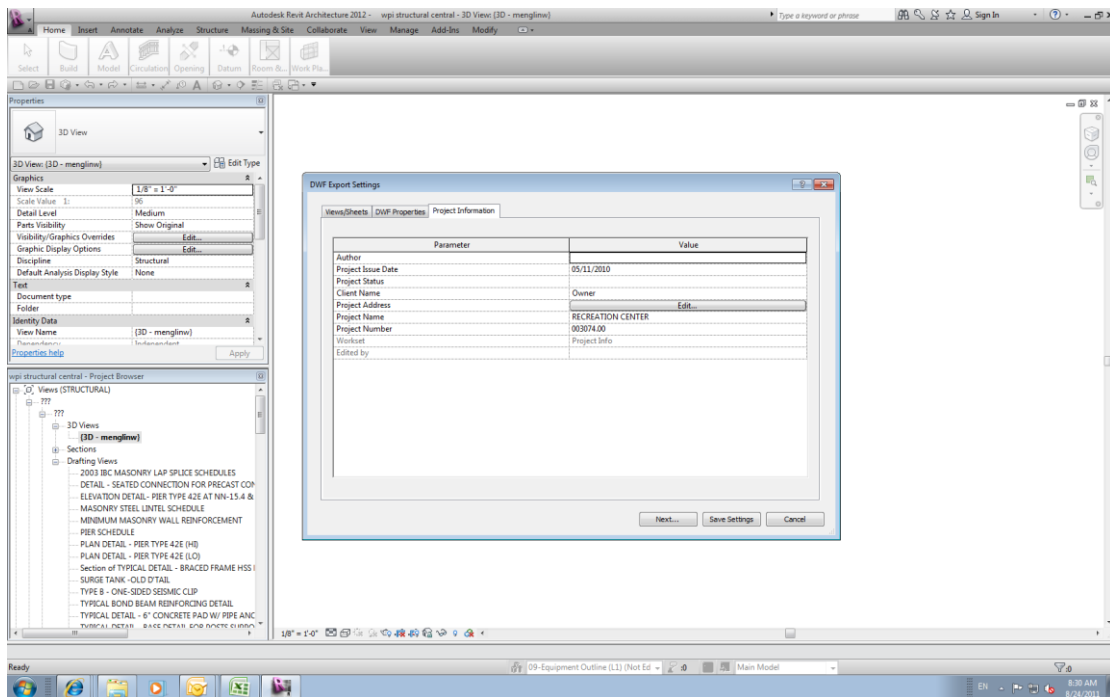**Figure 42: Export DWF. Format in Revit**

Figure 43: Project Information

Export Civil 3D site model as DWF file format.

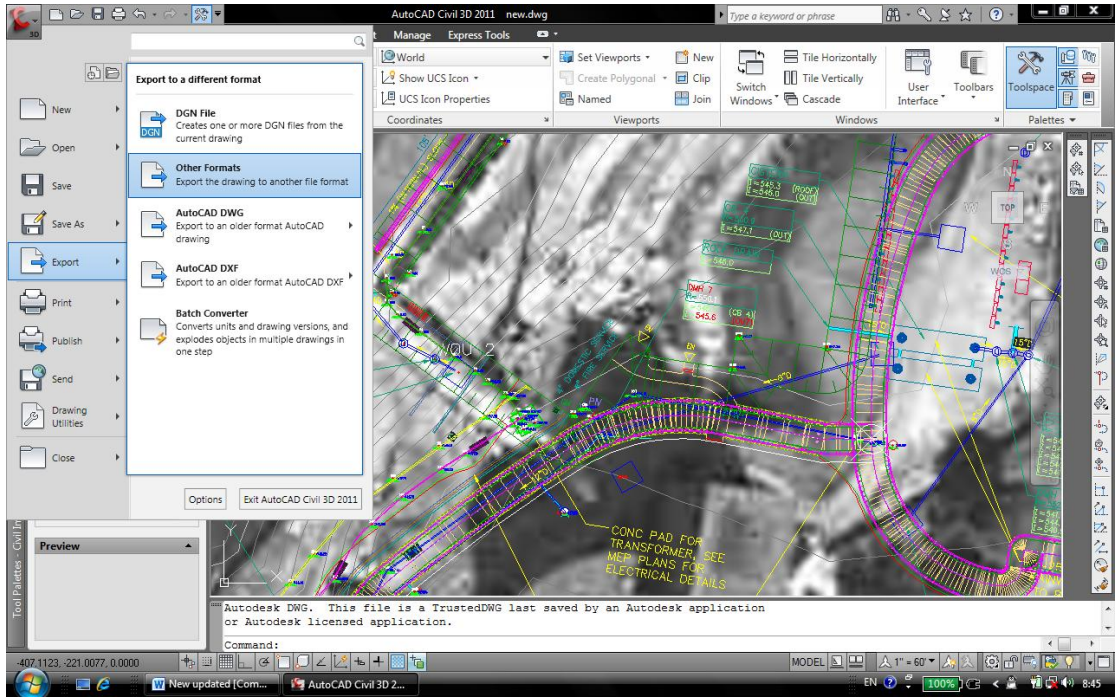Home>Export>Other Formats (Figure 44)

Rename it "site.dwf" .

Figure 44: Export DWF Files in Civil 3D

Open Navisworks Manage 2012, open "site.dwf" (Figure 45)

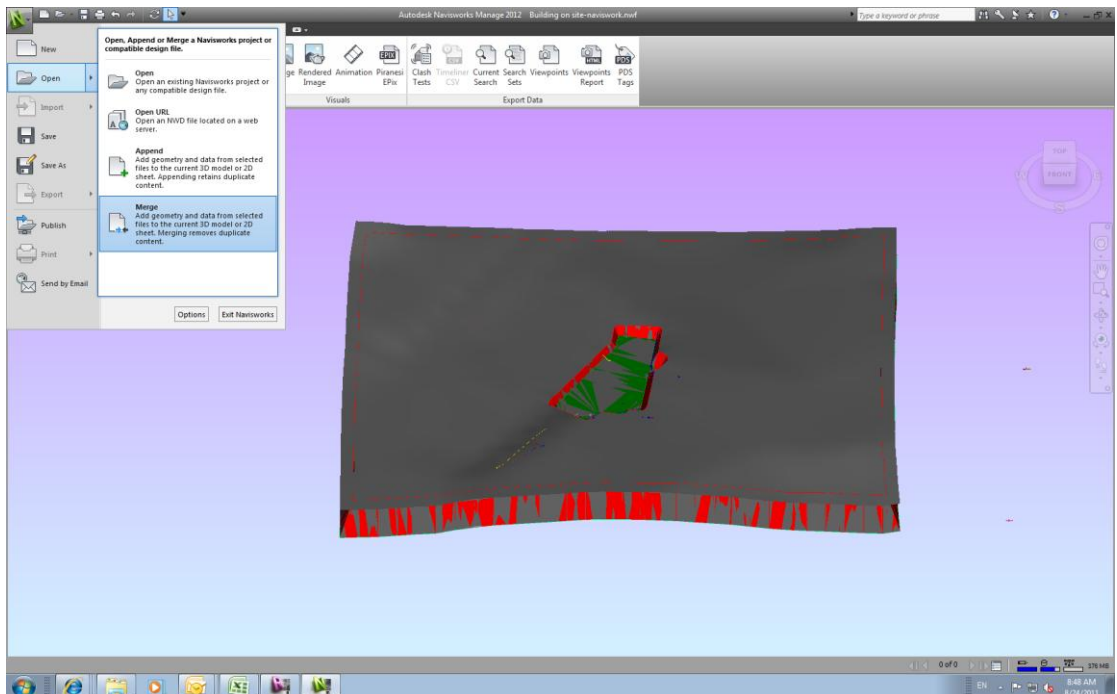Home>Open tab drop down>Merge, select "building.dwf"

Figure 45: Merge two models in Navisworks

The finished site-linked model would be as figure 23 shows.