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3D Earthwork BIM Design Process for a Road Project

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ABSTRACT: Building Information modeling is playing an important role in transforming the construction industry. It helped the industry with better visualization, minimum design errors, and excellent planning of the construction activities. Time and cost saving can be effectively achieved by using BIM for any construction project. It improves information exchange between all the project stakeholders. However, the development of earthwork 3D BIM is still underway and has not been fully implemented yet. This paper presents the study of a complete process for Earthwork BIM design using Autodesk Civil 3D. A real site road construction project is used as a case study to explain the process of earthwork modeling, starting from laser scanning to 3D model. Quantity take off calculation is very important part of any road construction project so during this study earthwork volume from two 3D earthwork model is calculated. The results obtained through this study will be the basis for future work which has been concluded in this paper.

KEYWORDS: Earthwork, Road, 3D BIM, Quantity take off, Civil 3D

키워드: 토공사, 도로, 3D BIM, 물량산출, Civil 3D

1. Introduction

1.1 Background

Earthmoving technology has rapidly revolutionized in the past few decades. The Building Information Modeling (BIM) has been proved as a very effective technology in the design and building construction, however, earthwork operations have not taken full advantage of it yet. The earthwork operations have importance role in any road construction project and it can cost about 25% of the total construction expenditure (Hare et al., 2011). The earthwork operations are the indication for the success or failure of the project,(Smith et al., 2000). Therefore, accurate estimation for earthwork is essential in the road project. The Digital Terrain Modeling (DTM) analysis for geometric design is used to create cross sections, profiles and earthwork. The DTM helps in volume calculation using laser scanning data and CAD software (Uddin, W., 2008). The earthwork process face various uncertainties and are influenced by numerous factors, ranging from natural to man-made. 3D BIM design is an effective way to communicate the information, relating project to the public and management (Easa et al., 2002). The visualization through 3D models has the capability to present the site conditions in its original form, understandable for allthe stakeholders (Elnimr et al., 2016).

Earthwork model generation process starts with the laser scanning, as it is an important technique to get the site topography and related details. By using this technology a detailed model of site can be created before and after the completion of work to determine earthwork quantities (Slattery et al., 2011). Laser Scanning creates an accurate 3D image of the site, which is easy to export the point cloud data to the CAD applications because of coordinates information (Jaselskis et al., 2005). Through this technology, thousands of point location can be recorded with higher density within the range of several hundred meters (Slattery., Slattery,

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2013). The extraneous points from the data can be removed by a careful examination of the point cloud data using the site photographs. Some software packages are also useful for the removal of such points from the data. The phantom points which may result from water or other reflective surfaces are required to be removed from data to get accurate terrain model.

The surface from the point cloud can be created by adopting the standard procedure. Earthwork volume calculation, without the use of the 3D model, is a tedious and time-consuming process, and inaccuracy in the calculations result in increased or decreased cost for overall project (Kim et al., 2014). Traditionally, in the earthwork projects contractors calculate the volume of the earth by counting the number of dump trucks, which is not an accurate and suitable method for quantity take off. The earthwork quantity is usually based on the cross sections along the alignment line, which represents the difference between existing and proposed ground surface (Slattery., Slattery, 2013). In earthwork operation, quantity takeoff has the essential role which leads to the demand of 3D model. (Calina et al., 2015) Calculated the earth moving volume using TopoLT program in conjunction with AutoCAD. The 3D earthwork calculation method provides higher accuracy than the conventional 2D method neglecting the terrain data error (Cheng and Jiang 2013). This research aims to design 3D earthwork models and then compare these models to calculate the volume at different stages of the project based on average end area method. A road real site project is used as a case study to create the earthwork model before the start of excavation work, and these models were regularly updated to compare the different earthwork surfaces as the project progressed.

1.2 Methodology

The study presented in this paper consists of three section. In the first section complete 3D earthwork BIM design process using Autodesk Civil3D is explained. The process explains the important factors involved in 3D modeling of earthwork. A case study of a road project in South Korea is presented in second section regarding the implementation of this process. Site excavated ground surface are used for 3D earthwork modeling. Third section involves the quantity take off for both models. The quantity take off is calculated for the earthwork models at different stages.

2. Earthwork BIM design process

Several design heuristic are to be considered for 3D earthwork BIM. Figure 1 illustrates the complete earthwork BIM design process from laser scanning of the site to model creation in Autodesk Civil 3D. The design process is covered in three major steps, which are 1) laser scanning: this section explain the procedure from laser scanning to noise removal 2) Tin model generation: process of importing points in Civil 3D to alignment line adjustment is discussed briefly in the section 3) Earthwork model: creation of surface profile to the final 3D earthwork model is explained in this section. Previous research shows that Civil 3D is being used for the visualization of surface models, especially in the infrastructures. (Bonenberg., Wei., 2015; Slattery., Slattery., 2013).

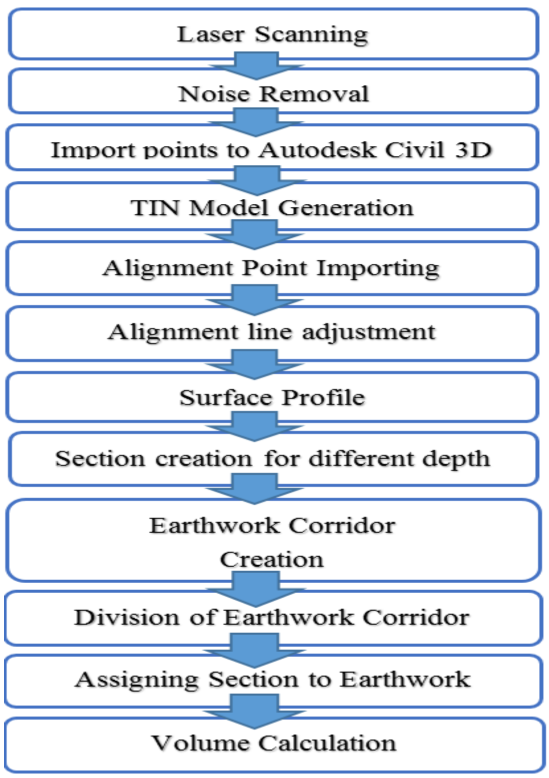

Figure 1. Flow chart for 3D Earthwork BIM design

2.1 Laser Scanning

Point cloud data has eminent importance in the 3D modeling of any real world object. Research showed that laser scanning is one of the fastest way for collection of point data information as compared to other processes (Tang et al., 2010). It is also proved as essential and fastest way for updating existing BIM models (Randall, 2011). A scan plan should be developed in order to have minimum number of scans to cover the whole area of interest while minimizing overlap before laser scanning. The point cloud data may exhibit extraneous point information due to the presence of construction material and equipment on site. (Tang et al., 2010; Hiremagalur et al., 2007). Extra care is required while scanning the area, to avoid capturing of moving objects which are difficult to remove from point data. The accuracy of point data collection is vital to ensure for perfect ground surface model. Leica infinity software is used for the removal and filtering of duplicate point data. Project site photographs are also useful for noise removal. Extraneous points can be accurately identified and removed by using RGB function.

2.2 Tin Model Generation

Point data is imported to the Autodesk Civil 3D after removal of extraneous points. Point data information in Civil 3D can be imported in PENZD (Point number, Easting, Northing, Elevation, and Description) or in other formats according to available data. The first step is to generate TIN surface model for the 3D BIM design in Autodesk Civil 3D. The TIN model has key importance in the roadway design and earthwork planning (Turk., levoy., 1994; Nassar et al., 2011). The topographical model of site can be visualized in 3D wire frame, conceptual and realistic view with visual style function of Civil 3D. These different visualization function can aid to remove the unnecessary points by examining the shape of surface. Various layers are assigned at each step for making design process more efficient.

TIN surface generation is followed by importing alignment line point information. Alignment line information data is collected from the 2D drawings. Point Data for ground surface and alignment line is separated in two different groups. Different style of each group will helpful to visualize both point data information separately. Alignment line or center line is an important component in the road designing and its optimization can affect the earthwork volume of road project (Jha et al., 2004). An alternative design of alignment line become easier through BIM process (Kim et al., 2014). Alignment line adjustment is a critical factor for the creation of accurate 3D model. Figure 2, display the incorrect adjustment of alignment line in 3D models. The earthwork section is not placed at a same elevation in the model at each point as shown in Figure 2. Section at alignment elevation point are higher than at other point which make the model incorrect to provide any design information. Accurate adjustment of Northing, Easting, and elevation value is required for perfect alignment line placement. However, alignment line elevation value cannot be adjusted to the ground surface. It is a tedious job to attain accurate elevation for alignment line on the ground surface. It is difficult to update the alignment line elevation during the progress of project excavation work. Optimization of alignment line become easier with the visualization of different design options (Kim et al., 2014). For removing all the possibilities of error in 3D model, alignment line is adjusted on proposed ground surface. These elevations are extracted through 2D drawings. Alignment line adjustment is also useful for surface generation at proposed ground and to obtain an accurate 3D earthwork model.

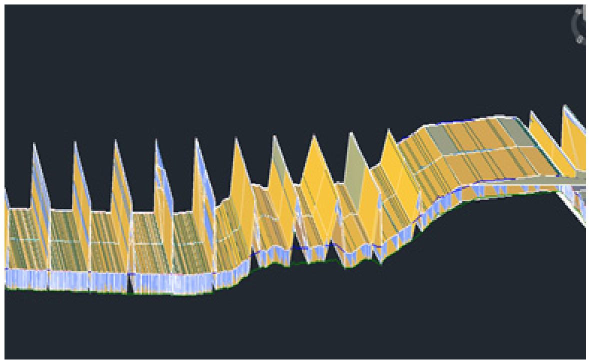

Figure 2. Incorrect alignment line adjustment

2.3 3D Earthwork Model

The first step for this process is creating surface profile. The profile provides the insight of the variation in elevation along the road length and is important role for assigning earthwork cross-section subassembly. Civil 3D profile function generates the surface profile along the alignment line for models. Careful Surface profile examination is helpful in

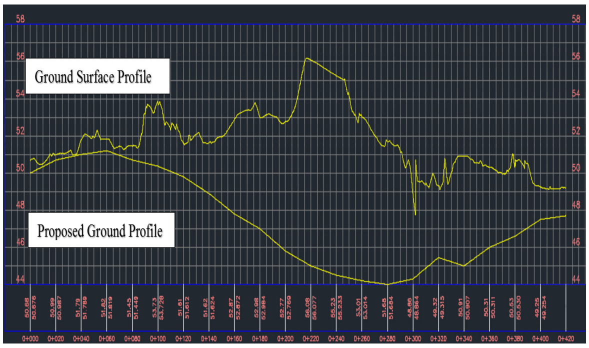

Figure 3. Existing and Proposed ground surface profile

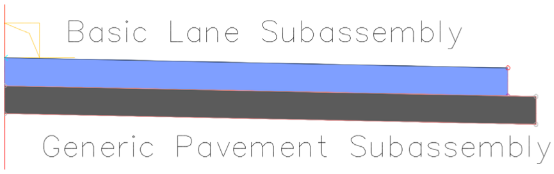

Figure 4. Basic lane and Generic pavement subassembly

attaining information of elevation at each station along the alignment line. New profile draw function is useful to test multiple design options to compare with original design. A new profile can also be designed on proposed ground level. An example of profile for existing ground surface and proposed ground is shown in Figure 3. It illustrate the difference of elevation at each station for excavation.

After Surface profile, next step is the creation of earthwork subassembly section. There is no specialized earthwork subassembly provided by the Civil 3D in content library. The subassembly is the geometry component in the corridor model (Holland., Mercier 2012). Civil 3D provide a wide range of subassemblies for road structures and pipelines. It also contains conditional subassemblies which define the cut and fill value along a road. Basic lane and generic pavement subassembly in Civil 3D content library is shown in Figure 4. Use of these subassemblies results in the step formation at the bottom face of 3D model.

The final 3D model generated through these subassemblies does not represent the exact earthwork model. Design requirement for 3D earthwork BIM cannot be fulfilled with these subassemblies. Earthwork section subassemblies are manually created in subassembly composer to solve these issues. The composer is based on visual basic functionality for subassembly design (Davenport., Voiculescu, 2016). Decision function of subassembly composer is used for earthwork section to automatically target the existing ground surface. These subassemblies are different from daylight subassemblies because they contains earthwork section information. Parameter assigned to the section are changeable according to design requirements. Width and depth parameter for a section can be calculated through 2D drawings. Excavation depth can be calculated by using the equation(1) at any station. ED (Excavation depth) on each station is achieved by subtracting LAE (Level after excavation) from CE (Current elevation).

$$ED = CE - LAE \quad (1)$$

These subassemblies are imported to subassembly content library in Civil 3D. The final step is generation of earthwork corridor model after defining earthwork section parameters. A corridor model consists of a 3D model having a surface, alignment line, surface profile and section design (Holland., Mercier, 2012; Rebolj et al., 2008). Existing Ground surface is selected in target surface option available in corridor model. The section will automatically adjust with ground surface. The model can automatically adjust design section to cut and fill with the help of conditional parameter along the complete road. Multiple sections for earthwork design can be avoided with this function.

3. Case Study

3D earthwork BIM design process explained in above section is implemented on a road construction project in South Korea. Figure 5 shows the geographic features of the case study site. The road project is about 600 m in length

Figure 5. Aerial view of road construction site

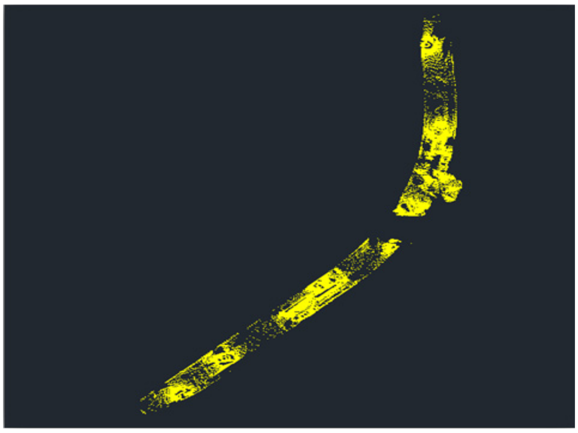

Figure 6. laser scan image of road project

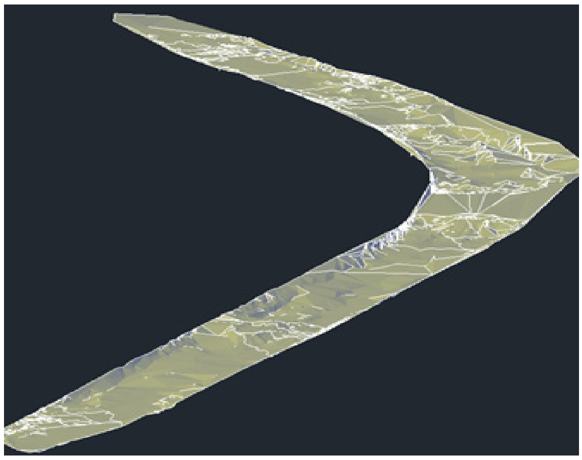

Figure 7. Conceptual view of existing surface

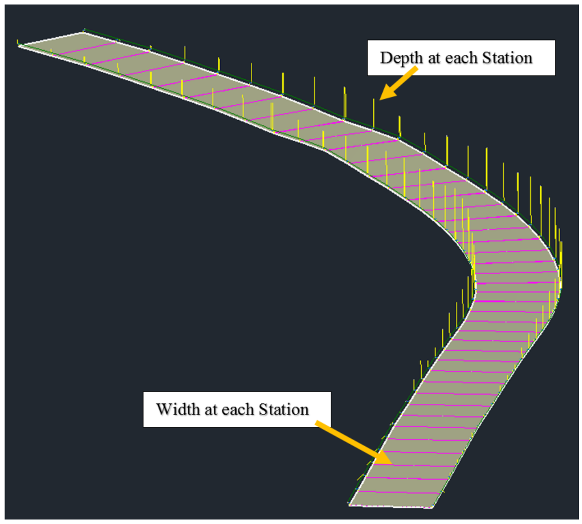

Figure 8. Corridor model structure

and consists of U-type and Box type structure. U-type area of road is long in length and open while Box type structure area is small in length and closed shape. The length of U-type road is about 400 m while box type is about 200 m. Laser scanning at the project site is performed two times at different excavation level The progress models are helpful in visualizing and monitoring of the project. Laser scanner is used to scan the site from six different locations in order to cover the whole project area. After three weeks of work, the site is again scanned using 13 different location for more accurate results. Multiple locations are used because it is more difficult to achieve all point data information from the location due to the presence of irregular terrain and structural component (Tang et al., 2010). More than 50 thousand points are collected from the site during first scanning, and about 60 thousand points are collected in the second scanning for the road site. The point cloud information contains a large number of extraneous points due to the presence of construction material and excavators (Tang et al., 2010; Hiremagalur et al., 2007). These extraneous points are removed through Leica Infinity software. Figure 6 shows the laser scan image of the site. The image shows some areas with less dense point cloud data or empty spaces which is due to removal of extraneous points. It is and also because some areas are far from laser scanning station Filtered scan points are imported in Autodesk Civil 3D for earthwork model. After importing alignment line information two separate point groups are created in order to differentiate between scan and alignment points. The TIN surface is generated for both models as it has key importance in earthwork planning (Greg et al., 1994; Nassar et al., 2011).

Conceptual view of the excavated ground surface is shown in Figure 7. Alignment line is adjusted to proposed ground depth as explained in the first section. The surface profile is generated to observe the variation in elevation along the alignment line. Section design for this road project is created in subassembly composer. The conditional parameter are assigned to the slope, so that it can automatically adjust in cut or fill state with excavation progress models. Uniform width of about 22 m has assigned to the cross-section. The depth of excavation varies from 0.46 m to 11.18 m at different stations in this project.

The final step is the creation of corridor model in which section for excavation progress model automatically adjust their depth according to design. Figure 6 illustrate the

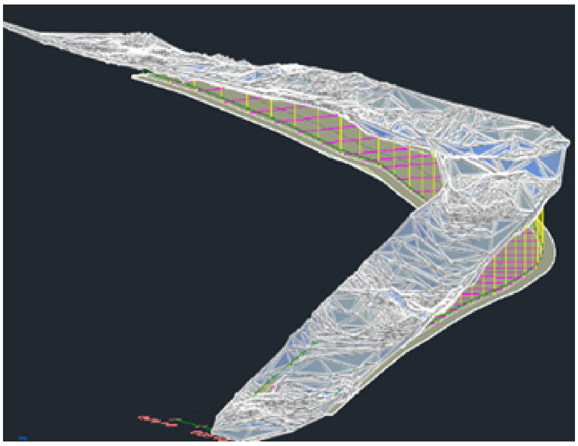

Figure 9. 3D earthwork BIM for progress work model 1

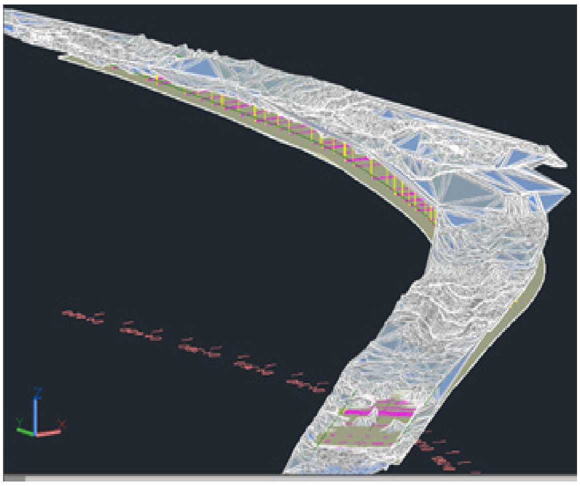

Figure 10. 3D earthwork BIM for progress work model 2

structure of corridor model. Vertical yellow line shows the depth of excavation at each station, horizontal pink line despites the width information. The final models for both progress surfaces are shown in Figure 9 and Figure 10. Realistic visual style has been used for the visualization of final 3D earthwork models.

4. Quantity Take Off

Quantity take off is an essential part of any project. Earthwork has a huge impact on project cost. Also, the wrong estimation of earthwork volume can lead to increase the project cost. It also help the contractor to better plan site equipment for earthwork. Project manager traditionally estimates the unexcavated volume of the site with the help of dump trucks. Mass haul diagram or rough estimation technique are also utilized for earthwork volume estimation (Michael et al., 2004). These traditional technique does not provide accurate earthwork volume for progress excavation. Earthwork cost will ultimately increase the project cost. 3D earthwork progress models help to estimate remaining excavation work more accurately. Earthwork volume for both models of road project are computed on the basis of average end area method in Civil 3D. (Easa, 2003; Aruga et al., 2005). This method gives more accurate results for earthwork terrain.

$$V = \sum L(A1 + A2)/2 \tag{2}$$

Volume is computed by comparing the existing ground with proposed ground surface. The initial volume estimated by the contractor before the start of excavation was more than 60000 m^3. The quantity take off of earthwork computed from the first excavation progress model design on Civil 3D is about 43188 m^3. Earthwork quantity for the second excavation progress model is calculated 33747 m^3. In three weeks 9441 m^3 soil was excavated. Earthwork calculation from 3D earthwork models helps the project manager to analyze the excavation work progress more accurately. These numbers also help for efficient planning of earthwork operation by more accurately calculating number of dump trucks and excavators required for remaining earthwork.

5. Discussion

Several critical factors are highlighted in this study for 3D earthwork modeling process. The understanding of basic heuristics is important before starting the 3D earthwork modeling. Basis heuristics are as following:

- Laser scanning should be performed with extreme care to eliminate extraneous points and special care is required when there are moving objects at site or if there is presence of water bodies.
- Change in reference point coordinate information can cause a wide range of error in point information.
- Extra attention is required during the removal of extraneous points so the orignal site points should not be removed
- Surface points and alignments points should be imported in same file format like PNEZ or PENZ.

- Alignment line information should be extracted accurately from 2D drawing, and it should be exactly adjusted to proposed ground for perfect 3D modeling.
- Earthwork section can be created according to the various design parameters and keeping in view the site requirement.
- Surface targeting is important in the corridor for visualization of accurate cut and fill shape of the 3D model.
- The existing ground and proposed surface comparison is important for earthwork quantity take off.

These heuristics are useful to create 3D earthwork BIM more accurately. 3D model generated from this process provides to visualize of earthwork information required for its planning. A large part of the research is, however, still to be done.

6. Limitation and Future work

This research presented the procedure for 3D earthwork modeling, however, the limitations faced during this research are as follows

- Area for the ground surface models need to be wider than the design section so the section slope can easily connect to the surface.
- Earthwork section is to be created for every new site according to its design requirements.

The study in this paper is a part of large-scale research project based on Fleet management using ICT technology. The proposed process in this paper is an impetus for further research in 3D earthwork project. In future research, this 3D modeling technique will be applied to different road and other construction projects. Different estimation method will also be used to estimate earthwork quantities from these 3D models. Study of this process will also help in BIM module development. 3D models generated through this process can also be utilized for machine guidance. This modeling process will help in 4D and 5D earthwork BIM study. Future study will also be carried on BIM content library for earthwork section.

7. Conclusion

The purpose of this study is to fill the research gap in the field of 3D earthwork BIM. The complete process of earthwork modeling from laser scanning to 3D BIM design generation is explained in detail. This process is formulated after going through trail and error process. A case study of road project in South Korea is used for implementation of this design process. Earthwork quantity take off for two excavation work progress models is calculated and compared with the help of 3D BIM. In the last section of this paper important heuristics of 3D modeling are discussed and also limitations for this process are highlighted. Future research in 3D earthwork BIM and its merits are also described in details. The study in this paper will upgrade the traditional method of estimating earthwork volume. These results are useful to eliminate the error in estimation and it can optimize the earthwork cost on the road project. Project manager decision for earthwork planning will become more efficient with known quantity take off with this study. It is also a useful tool for earthwork site progress monitoring.

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