Flexible Earthwork BIM Module Framework for Road Project

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Abstract

Development and expansion in the cities have increased the demand for road construction projects in different regions of the world. The construction projects in the modern era require the utilization of latest technology. BIM and its collaboration with other technologies like GPS, UAV, AR/VR, and telematics have successfully proven their worth in provision of a solution to various construction industry problems. Innovations in BIM process by researchers are a remarkable asset for planning and visualization. Earthwork in road sector demands further research to achieve better planning, visualization and improvements in productivity using BIM process. The study in paper presents a user-friendly flexible earthwork BIM module framework for the road projects and explains the complete modeling process from point data collection to final design.

This study also discusses a model partitioning technique which can be used for the division of earthwork BIM model for better visualization and implementation. This method is useful for the primary design information modeling of earthwork at each section and is easily useable for the multi-phase construction project.

Keywords

Earthwork; 3D BIM; Road; Module; Partitioning Technique.

1 Introduction

The technology revolution has made the exchange of information easier than before. It has a greater impact on construction industry where the information exchange is time-consuming and complex. Building Information Modeling (BIM) is considered as an important source by using 3D design models during all construction phases, to exchange information in an efficient manner [1]. Researchers have provided an excellent contribution in 3D BIM for exchanging design information and its collaboration with other technologies. However, few areas of construction industry such as earthwork operations require its practical implementation, as they have not attained full benefits of BIM till now. The Earthwork operation has a huge impact on construction cost, especially in road construction projects. Previous studies have shown that about 25% of construction cost is associated with earthwork operations [3], and it increases the demand for accurate estimation. For better knowledge of earthwork process, variable aspects of design and other factors from natural to man-made must be accurately analyzed. 3D model is an efficient tool to visualize these factors in original form and are easily explainable for all participants of the project [4].

In 3D modeling as a first step, it is important to collect site information data and analyze the ground surface for accurate models. For this step, Jaselskis considered the laser scanning procedure for accurate visualization of the site and its adoption in CAD platform [5]. It is a faster and more efficient way of collecting data as explained by Slattery [2]. Different researchers have provided a remarkable effort regarding earthwork surface modeling and data collection technologies for 3D models [6,7]. Randall [8] explained laser scanning importance for BIM modeling, and Sepasgozar [9] described the challenges being faced in using these technologies. Slattery, Kirchbach, and Elmqvist [2, 10,11] explained terrain surface modeling of the site using TIN along with various other solutions. All of the research work performed previously have mainly focused on data collection and 3D modeling of the ground surface, however, complete 3D earthwork BIM design was not discussed. The platform like Autodesk Civil 3D mainly utilized for the TIN surface modeling of site and earthwork estimation of road design [12]. There is no particular function provided for earthwork BIM modeling. Software like InSite SiteWork [13] and Earthwork software [14] provided a solution to many earthwork problems like trench excavation, topsoil replacement, and earthwork estimation, but 3D earthwork BIM support function was not considered. As per our knowledge, no research has been carried out involving module for 3D earthwork BIM modeling.

Waqas [15] and Hassnain [16] defined the complete 3D earthwork BIM process along with its heuristics for a road project. However, this study is an improved version of previous work, and it involves utilization of 3D earthwork BIM process in the development of Flexible Earthwork BIM module. The first section of the paper explains the complete 3D earthwork BIM process for a road project. The second section of the paper explains the partitioning technique of 3D model used in the module for primary design information modeling at each segment. Jingbin Hao[17] used partition technique to partition solid models into submodels segments to precisely analyze the model. Watershed technique is also utilized to partition 3D solid meshes by [18]. The previous technique utilizes surface partitioning concept, however, it cannot be utilized in 3D earthwork modeling. The author explains the basic concept of partitioning in this study for 3D earthwork models.

The proposed 3D earthwork BIM design process and partition technique used in the module will be helpful for all stakeholders involved in construction industry. The module framework presented is undergoing the testing and development phase. It also contains earthwork section library for 3D modeling. The study will be supportive for further research work in 3D earthwork BIM and its utilization in various construction projects.

2 Methodology

This paper presents the Flexible earthwork BIM module which is based on 3D BIM process and model division technique for a road project. The module is in the developing and testing phase. This paper explains the module in two sections. The first section of the paper describes 3D earthwork model generation in the module. The complete 3D earthwork BIM process starting from data collection to the final 3D model design in the module is briefly discussed in Section 2.1. The 3D model partitioning technique along with its importance is explained in Section 2.2.

2.1 BIM Modeling Process

Accurate 3D model is necessary to visualize major design information of the project. To achieve a perfect 3D model multiple factors are required to examine. 3D earthwork modeling process in this module is divided into three major steps. The first phase involves data collection of the site to TIN surface model generation in the module. The second phase includes the alignment adjustment for better 3D modeling. The third major step is a selection of earthwork section according to design requirement for the final 3D model. Earthwork design information can be visualized with the help of a 3D model. The Flow chart explaining the complete process is shown in Figure. 1.

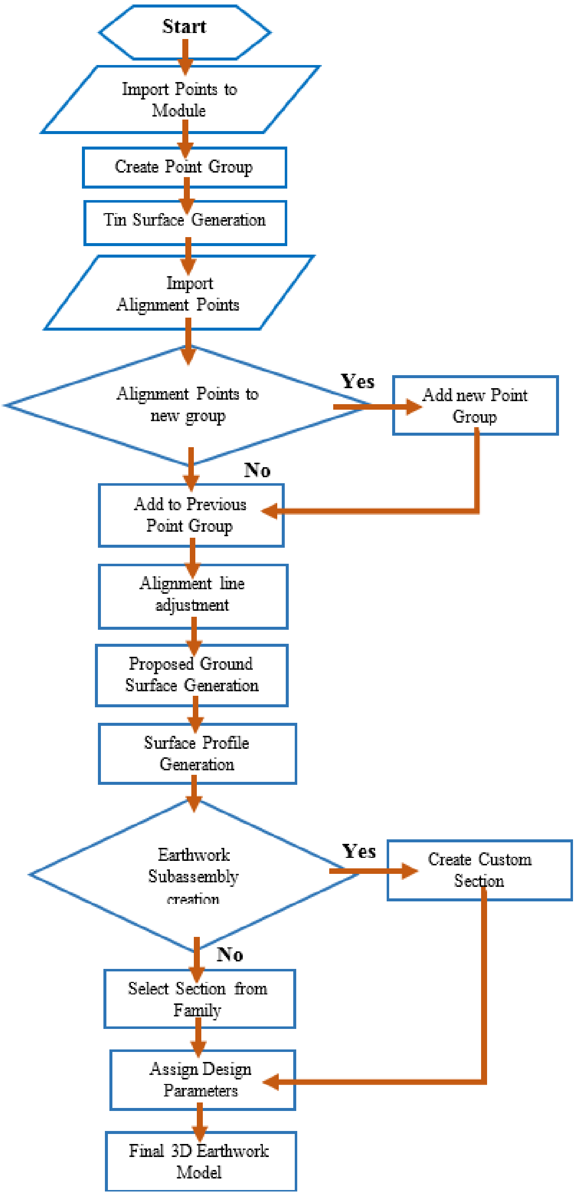


Figure. 1. 3D Earthwork BIM process

2.1.1 Point Data Collection

Data collection of the real construction site is the first step towards 3D modeling. Traditionally, different surveying techniques were used for collection of point data. Nowadays, laser scanning is considered as an easier and faster way as compared to traditional surveying equipment [6]. Laser scanning made the analyzing of a ground surface model more easy and efficient. A detailed plan of laser scanning position is required to collect maximum details from the site accurately. The irregular shape of the site increased a maximum number of scanning position to gather every possible detail in the form of point data. Scanning on the site has the chances of obstruction from construction materials and equipment. They will store as an extraneous point in the point data. It will cause a disturbance in the accuracy of acquired data. Extraneous points of moving object are difficult to remove so extra care has to be taken in such situation. Removal of all extraneous point is necessary after collection of point data information for 3D models. Extra attention is required during removal of points to improve the accuracy of site information. The RGB function of different software help to perfectly identify and eliminate these points.

Point data after filtration is saved into a .txt file format. Data is saved in global coordinates system which contains information of three axes X, Y, and Z. These coordinates information is imported into Flexible BIM module to create point group which is useful for organizing and editing point data. The next step is to generate a TIN model for 3D visualization of the ground surface [2]. The digital representation of actual site has a key role in earthwork planning especially for road projects [19, 20]. 3D model coordinates are required to synchronization with actual site northing, easting, and elevation value for accurate information. TIN surface model can be updated or edited by changing the values of coordinates. The TIN surface contains a large number of triangles depend upon the number of points captured from the site. To analyze site topography for the earthwork planning, the surface model can be visualized in different visual styles available in the module. These styles include 3D wireframe, conceptual and realistic views. It will also assist the designer to analyze information in various views for accurate 3D modeling. Layer function of the module can be utilized to visualize each component of 3D model separately and to assign different colors for identification

2.1.2 Alignment Line

Alignment adjustment is next major step after TIN surface generation for 3D modeling. It is considered as a most important step in 3D earthwork model of road design. The alignment line points of road design can be collected with the aid of 2D drawings. These points contain the coordinates values of X, Y, and Z similar to ground model data. The module gives function to add alignment point data into separate point groups and has given the advantage to edit or manage both data efficiently and without overlapping. Optimization of alignment coordinates value is significant for earthwork quantities in road project [22]. The 3D model will also assist to give various alignment line alternatives to improve road design [21]. Alignment adjustment is necessary to achieve perfect 3D model at each stage of earthwork. As the earthwork progress, it will be hard to achieve the Z value of alignment point according to the new ground surface. The 3D model will lose its effectiveness if inappropriate adjustment of Z value for the point is made. Figure 2. Illustrates with an example of a 3D model where the erroneous adjustment was made.

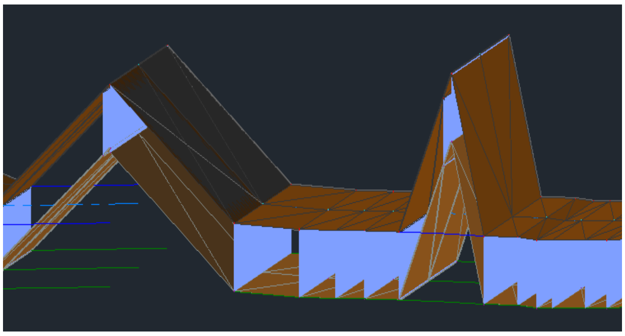


Figure. 2. Adjustment of Erroneous Alignment.

On the contrary, to adjustment problem a new approach of alignment adjustment is used in this flexible module. Z coordinate value of alignment point is adjusted to excavation depth which will eliminate erroneous adjustment. Model for excavation progress work will become easy and quick to design using this approach adopted in the module.

3D visualization of excavation depth can be achieved by making a TIN surface. The module utilizes alignment point to generate a TIN surface which contains all three X, Y, and Z coordinates value information. This information can be utilized also for partitioning technique and side slope surface generation. Design depth in the model will automatically change if any point information is changed. Module function of profile help to visualize depth difference between ground surface and proposed ground after excavation at each station. Profile main role is to observe elevation difference along alignment line [23]. Multiple options of the profile can be drawn and analyzed for the 3D model. It is also important factor like alignment for accurate 3D earthwork BIM according to the actual design.

2.1.3 3D Earthwork Model

Selection of earthwork section is a key factor in designing the final 3D model. Visual Basic programming API function is utilized for generation of earthwork section content library. Various earthwork sections are designed which are commonly used in road work Detail explanation of for earthwork section library algorithm will be presented in future work. Earthwork section is the geometry component of the final 3D model. It contains complete design parameters information of width, slope, and depth. These values of the section can be changed according to the design requirement. The designer can select any section of the content library or can create an own custom earthwork section by utilizing module functions. Parameters are assigned to the section after selection from library or creation. Section design parameters are collected through 2D drawings [15]. 3D model can be effected with parameters values, as attention is required while calculation of width, slope, and depth from 2D drawings.

The last step in BIM process is a generation of earthwork corridor model. It depicts the final 3D model which contain complete information of earthwork design [12,24]. 3D model is the composition of the surface, earthwork section, alignment line, and profile in the flexible module. Change of any major element will eventually change the 3D model. Excavation depth is required at each station along the alignment according to design as explained by Raza [15]. This increase the requirement of multiple section creation according to design at each station which is a time-consuming process. The section design requirement can be eliminated by utilizing the flexible module functions. Surface targeting function available in the module will automatically adjust the section with the ground surface. The slope of the section will target the ground surface and eliminate the use of different sections for one model. An additional function of making both side TIN surface in the Flexible module is provided to make accurate design model. The module will generate right and left side surface of the model by joining points of proposed ground and surface ground. The function can also be utilized to make a surface for the section slope. The surface generation will also utilize in partitioning technique. An example of 3D earthwork model design through this process is shown in Figure. 3. Similar models will be designed in the module.

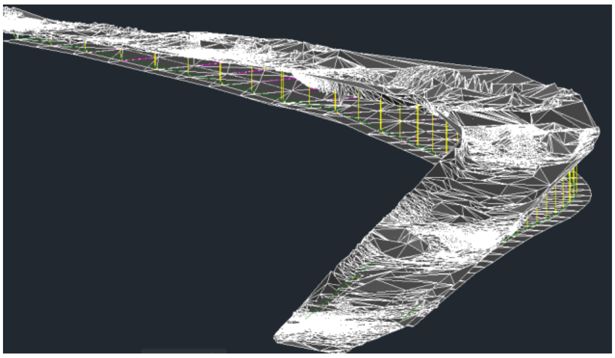
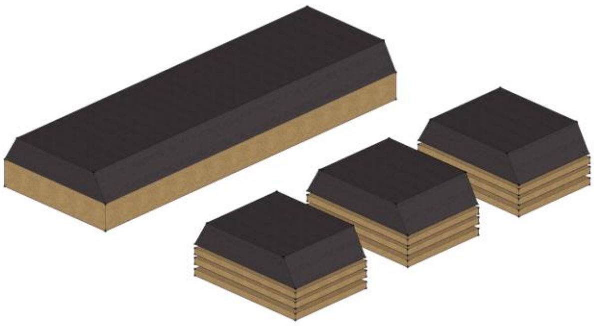


Figure 3. An example of 3D Earthwork Model

2.2 Partitioning Technique

The final 3D earthwork model generated through this approach is based on alignment line, surface, and section design. To model primary design information at each point in 3D earthwork is monotonous work. During the multi-phase construction work, various design changes occur due to site condition. Modification of design parameters at any segment will effect complete model as it is integrated and flexible. Partitioning technique function is introduced in the module taking into consideration the above-mentioned problems. This technique will use TIN 3D model to slice into horizontal and vertical segment like a surface model. Figure 4. illustrate an example of cutting of integrated surface model into different segment along the vertical and horizontal plane. Jingbin Hao [17] used partition technique to partition solid models into submodels segments to precisely analyze the model. As nature of the surface model is not similar to the solid

Figure. 4. Surface Model Partitioning



Model or tin model for slicing in various segments. Triangular network surface model is utilized for this purpose. TIN model is divided into smaller segments of points, lines by using explode function. These smaller segments recognized by the module to convert into the alternate triangular network by using line offset and mid-point method. The boundary is regenerated for each segment created in the new model. This method will aid to divide earthwork corridor model into multiple segments according to planning requirement. These segment will be in vertical and horizontal form.

Detail design information can be linked to each segment of the model. Soil attributes, start date, end date, slope information, underground facility information can be easily linked. This approach used in module provide a solution to the efficient management of work progress and eliminate redesigning of the complete model. The previous approach in different software like Autodesk Civil 3D used a station based partitioning technique that is not quite useful for detail design information modeling [12]. Corridor model from Autodesk Civil 3D can also be imported in this module for partitioning of the model. Alignment line is saved in .xml to be used in the module as the center line for partitioning. Corridor model along with surface model is divided into the separate triangular network. The complete network model is saved, and a quick view function of the module and it will regenerate whole new TIN model. The horizontal and vertical segment will be achieved through module as explained above. Construction ID, start date, end date, soil attributes will be linked to multiple segments and save as a data sheet. This information of multiple segments in data sheet can be exported to Excel file for future use. Partitioning of corridor model as an example is shown in Figure 5. along with a framework of the module in Figure 6.

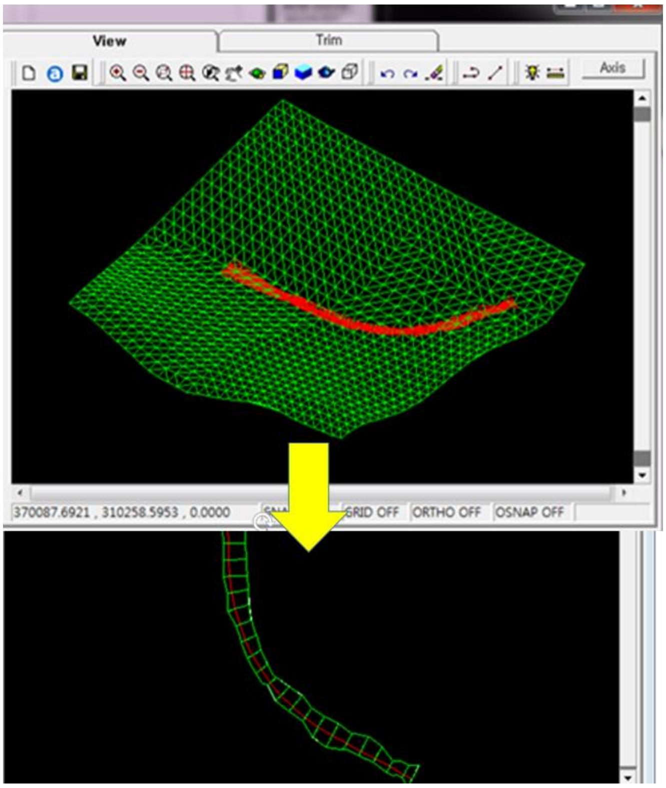


Figure 5. An example of Corridor Model Partitioning

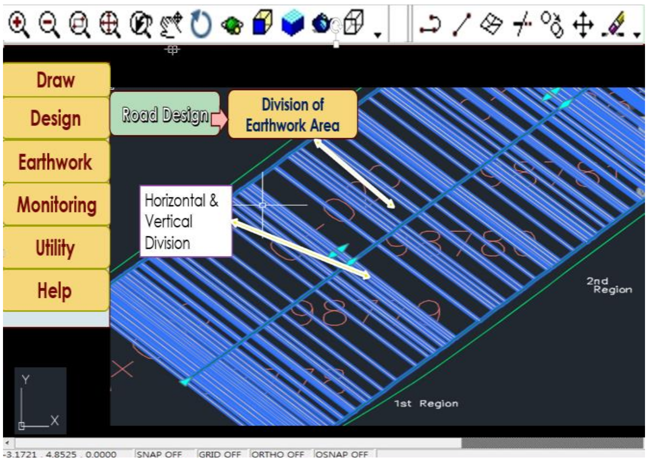


Figure 6. Flexible Earthwork Module User Framework

3 Conclusion

The purpose of the module framework presented in this study is to cover the knowledge gap of 3D earthwork BIM in the road project. In the first section of study complete 3D earthwork BIM process for a road project is discussed. It is divided into three major step from data collection to final 3D Earthwork model. The process can help to provide a complete visualization of earthwork design information in the 3D model. It's hard to deal with an integrated object during various construction phases where multiple design changes can be expected due to the site condition. The paper presented an important partitioning technique for small equal model segmentation to deal with the integrated object. It is useful in assigning the attributes at a different level for better managing earthwork design model. The technique presented also provides the basis to link required project information to each segment of Earthwork model. The information contains soil attributes, ID, start and end date, slope information. Flexible Earthwork module automatically makes changes in the entire model or segments if any design parameters are changed. An earthwork module system is under development based on this partitioning technique algorithm and 3D Earthwork BIM process. Visual Basic 6.0 programming language tool is used for the development of the module. It is supported in the Window 7 operating system. This module is also compatible with other software like Civil 3D

The study could be helpful in producing future research work on 3D earthwork BIM at different construction projects. The future work of authors involves linking 3D earthwork model with schedule and cost for 4D and 5D BIM. The development of improved earthwork BIM content library is also in progress. 3D models generated could also be utilized for machine guidance under the large scale fleet management research using ICT Technology.

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