# PAD Based 3D Earthwork BIM Design Module for Machine Guidance

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**Abstract –**

**Building Information Modeling (BIM) technology developed in the recent decades and provided a new perspective which shifted the trend from simple 2D drawings to intelligent 3D modeling. BIM is usually applied in many construction fields, however, it is not very common in earthwork projects. Earthwork is one of the primary component in any construction project especially in highways, dams etc. In the earthwork it has become possible through BIM to monitor and analyze the changes in model accurately. This study presents a discrete module system devised to support the Pad based 3D Earthwork BIM design, topographic modeling, and earthwork volume calculation. In the case of a slope, the direction and inclination of the slope can be incorporated into the design. The point cloud data obtained from GPS survey and Laser scanning process which can be then used to create TIN (Triangulated Irregular Network) surface and ground mesh. It provides a 3D BIM design compatible with software like Autodesk Civil 3D and also with Machine guidance system. This paper discusses the importance of Pad based earthwork design with its practical site application and also presents a case study using Machine guidance. The results of experiments on construction projects show that this approach can be effectively used for earthwork operations.**

**Keywords –**

**BIM; 3D Modeling; Earthwork; Machine Guidance**

## 1 Introduction

Earthwork operations possess a significant value in any construction project and can cost about 25% for the overall project budget. The estimation and planning for earthwork operations directly impact the cost and duration of the project, and these operations signify the success and failure of the project [1]. The earthwork operations also required the use of modern technology like other construction industry. The advent of new technologies also leads the construction industry in utilizing the modern techniques, especially in the earthwork process. The machine guidance system is one of such examples which allows the operator to work more efficiently by using the design on the display screen. The operator can use 2D or 3D design which helps in eliminating the traditional surveying methods which can create hindrance in the smooth operations [2]. The virtual 3D environment is also very helpful to check the shortcomings and for integration of design with construction process [3]. In the construction industry, there are several methods and software in use for the 3D modeling. It is important that such models contain all the essential details regarding surface. Different researchers adopted simulation approach for the earthwork planning to make it simple and practical [4].

The pad-based design is relatively easy to implement at the construction site and it is more efficient for building projects. However, this method can also be applied to other infrastructure projects for design and quantity estimation. There are different tools for earthwork estimation based on prismoidal or average end area method [5]. The average end area method gives higher accuracy in results with distance less than 30 meters between two cross sections [6]. The surface to surface method for earthwork volume calculation have higher accuracy than the average end area(AEA), and when the cross section interval is decreased, the AEA method provides more accurate results theoretically [7]. The digital terrain modeling (DTM) helps in volume calculation using laser scanning data and CAD software [8].

This paper outlines a new approach to earthwork design with the development of module system which significantly calculates the actual earth volume and generates a TIN surface for machine guidance. This method has importance in generating TIN surface which can be used for visualization of the 3D model as well as for the machine guidance system. Conventionally, the conversion of the 2D model to 3D is a cumbersome and tedious process [9]. The module is developed using visual basic programming and is compatible with the

CAD based commercial software. It is capable of targeting another surface from Pad, slope generation, volume calculation, and the creation of a model for machine guidance. The machine guidance technology has replaced the staking process and labor intensive survey work [10]. This technology is primarily used for earthwork projects. However, it is also useful for other operations like paving and lifting [11]. The integration of IT based system with the earthwork site results in higher efficiency and productivity. In earthwork process, the proper flow of information is essential as it can increase the transparency and lead to process improvement [12]. This module provides an easy approach for the model generation with its user-friendly interface.

## 2 Machine Guidance

Development of the machine guidance system in the construction industry is one of the most important reasons for using three-dimensional model. In the AEC industry traditionally 2D design drawings are used for construction operations which do not contain the elevation information. However, it is required to convert such drawing plans to compatible 3D models for machine guidance. The successful automation at the site is only possible if the designer is well aware of crucial factors in the design [13]. The 3D digital terrain design model is usually used for machine guidance. These models provide the information regarding elevation and terrain design to the operator through digital screen mounted in the cabin of earthmoving equipment.

Many researchers have identified the enhanced quality and productivity in the construction projects using automated machine guidance [14]. The modeling for the machine guidance system also improves the planning for the construction process with less rework on the designed model [15]. Use of such technology provides higher accuracy with less time and reduced cost. The operator of the earthmoving equipment can effectively visualize and move around the site using equipment position on the design model [16]. Different sensors are used on the excavator at the bucket, arm, and boom. These sensors provide the exact position for the bucket in the machine control system in the cabin.

## 3 Methodology

This paper presents a new BIM-based module system for earthwork operations. Visual Basic 6.0 is used as the main software language for the development of this module, and it uses Windows operating system. The system is developed in conjunction with CAD engine to produce 3D shape information. This module is an independent program and compatible with the other commercial design software like Autodesk Civil 3D. This research presents the PAD based technique for the modeling of earthwork design. It applies the volume calculation method which uses projection and interpolation for accurately calculating the earthwork volume. The earthwork design system components are presented in Figure 1.

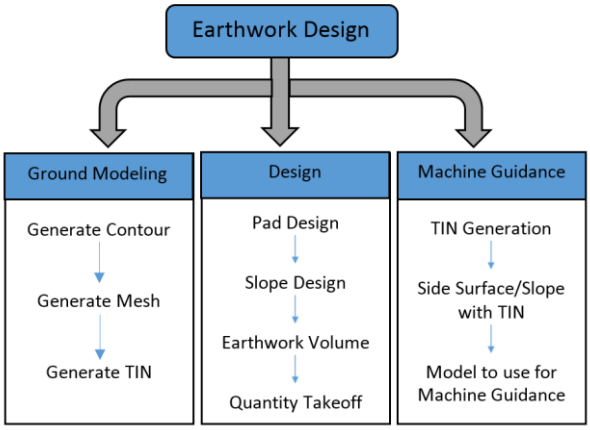


Figure 1. Earthwork design system components

The module has simple and user-friendly graphical user interface (GUI) which is shown in Figure 2. It has import function through which ground surface in the form of contour or TIN can be directly imported. It is also capable of importing point cloud data using .mdb file and generate the ground TIN surface. The Pad surface is created by providing the design elevation with co-ordinates information. The Pad based design can also be drawn on the topographic model with the desired altitude value, as all the points on Pad have the same elevation.

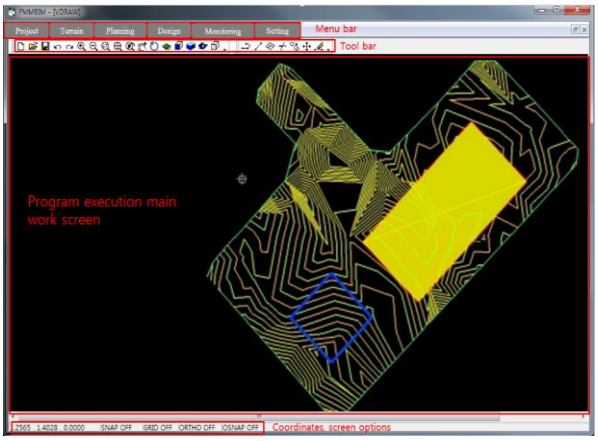


Figure 2. Module main screen

The TIN surface is automatically created using points in the Pad area. However, the next step in the

design is to connect the Pad with the existing ground surface for which the projection angle is required. Depending on the site requirements it is possible to generate the projection from the Pad surface in vertical or slope form, as the system can calculate the volume in each case. The program can calculate the cut and fill volume at any given section along the length of design Pad. The process of volume calculation is explained using flowchart in Figure 3.

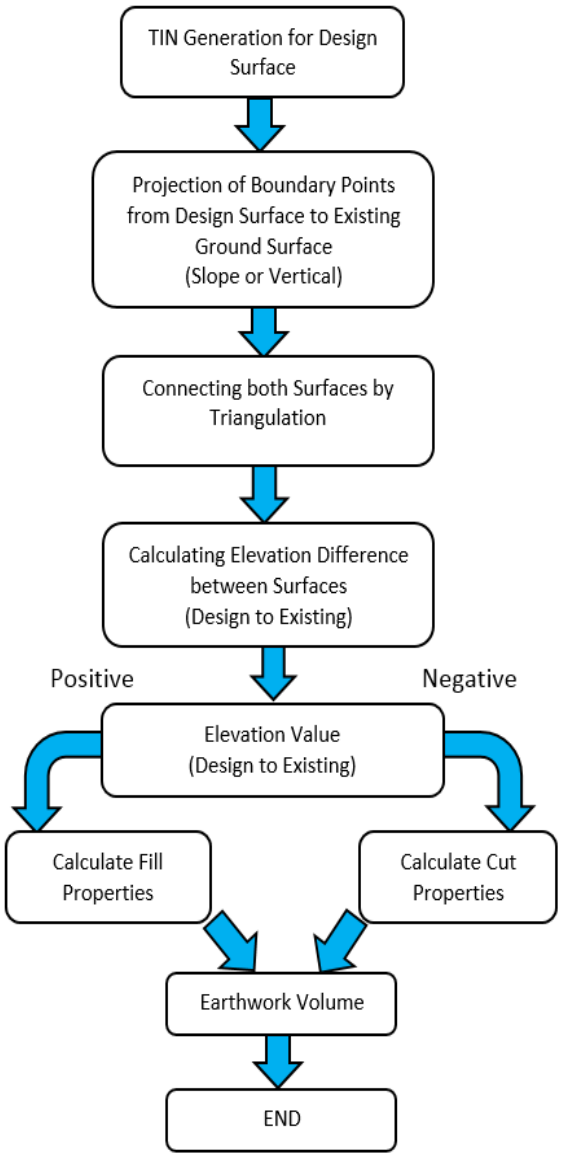


Figure 3. Flowchart for volume calculation of 3D model

Traditionally, average end area method is used for volume calculation based on the average area between two consecutive cross sections.

$$V = \frac{L}{2} * [A_1 + A_2]$$

Where A1 and A2 are the areas of cross-section and L is the distance between these cross-sections. It is challenging to use this method continuously for the nonlinear sections [17]. However, this module used the surface to surface method for better accuracy. A new surface elevation is calculated based on the difference between two surface elevations using the location where the edges of triangles intersect the two surfaces as shown in Figure 4.

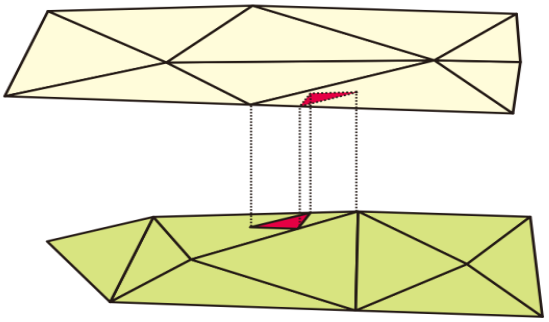

Figure 4. Surface projection illustration

It is important to know the elevation difference between existing and planned ground surfaces. The existing and proposed ground TIN surfaces are created using survey and design data. In the case of the Pad projection with no slope to the existing ground surface, the triangular network for side wall is generated between two surfaces. In this case, ground and design model share the same (XY) coordinates with the only difference of elevation. By using Z (elevation) value, the quantity can be estimated by triangular columns volume. If the Pad elevation value "Z" is lower than the ground TIN surface the volume is calculated as Cut, however, if the designed Pad is located at a higher elevation than the ground surface, the fill volume is calculated. A polyline is drawn along the Pad surface in a longitudinal direction from one end to the other for dividing the area into equidistance stations. The module also provides the equipment monitoring function. The design drawings in the module are saved in a **.dwg** file format which is converted into a **.dxf** file using Autodesk Civil 3D. The 3D design model with DTM (Digital Terrain Model) is then available for use in the machine guidance system.

## 4 Case Study

The following case study aims to check the practical application and the validity of developed module system. The model is designed using the Pad based module and is verified on site for use in machine guidance system.

A site in Seoul, South Korea is selected as a pilot project to test the developed module system. The area under study is not in regular rectangular shape. The site topographic data is collected using laser scanning, the 3D laser scanning technology provides higher density data as compared to traditional surveying methods. Ground contour data is imported into the module and using its TIN generation function the surface is converted into TIN. Figure 5 presents the original ground surface model in contour and TIN form.

A rectangular area is selected, and Pad design is drawn on the BIM-based topographic model. The Pad dimensions are based on required length and width at the site. The design altitude value is then provided to the Pad, as the whole surface have same elevation value. According to design and site requirements, it is possible to design in slope and vertical form, and the system is capable of calculating the volume in both cases. Figure 6 shows a Pad design with the slope, projecting to the existing ground surface. The outer boundary is indicating the connection with the existing ground surface, and inner rectangular marking depicts the Pad design surface.

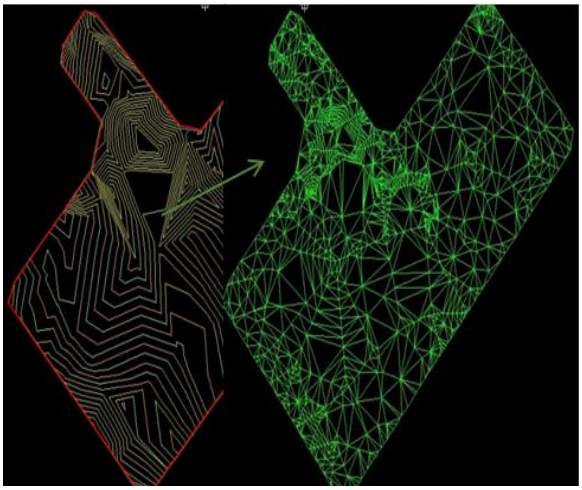

Figure 5. Ground surface model in contour and TIN form

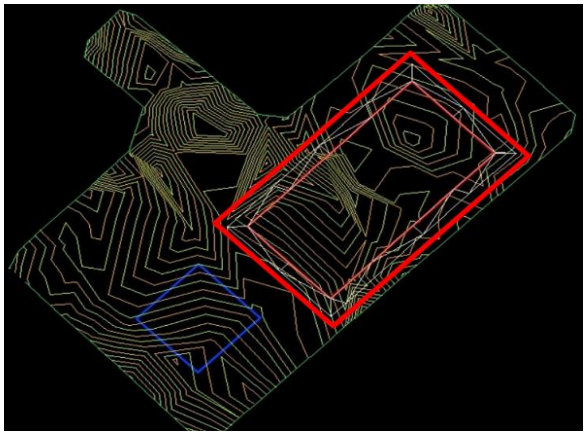

Figure 6. Pad-based design with existing ground surface

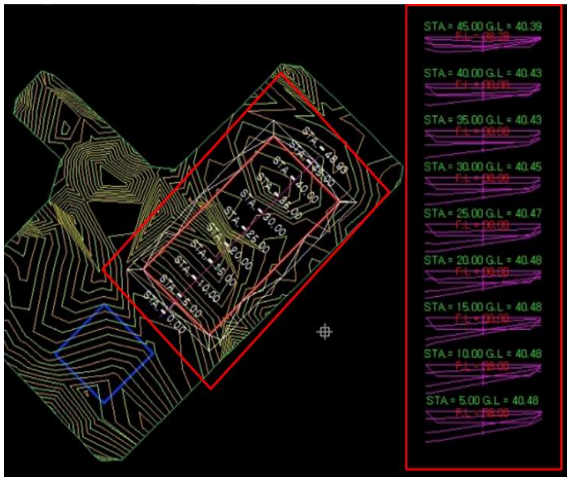


Figure 7. Pad design with station information

The Pad design surface is then divided into stations along its length as shown in Figure 7. The ground level elevation can be seen at any station. It provides the function to divide the Pad into stations with equal or different length. The Pad based design file having TIN surface is imported in Autodesk Civil 3D and saved in .dxf file format. The machine guidance control panel requires the TIN file in .dxf file format. The files with TIN surface are only visible in the control panel of earthmoving equipment. The Pad design file is then imported into the machine control panel. Figure 8 shows the view of machine control panel for the operator in the earthmoving equipment.


Figure 8. View of machine control panel

## 5 Conclusion and Future Study

This paper provides the information regarding Pad based BIM module system developed for the earthwork design. Visual Basic 6 is used for development of this module in conjunction with the CAD engine. The topographic modeling function supports 3D BIM design using the point cloud data obtained from laser scanning. It is possible to draw and design a Pad on the 3D ground with consideration of slope and vertical planning. For the volume calculation of cut or fill in between Pad design surface and existing ground, this module used the surface to surface method for better accuracy.

The developed module is capable of creating a TIN model for use in machine guidance system. A case study has proved the validity and effectiveness of this module for earthwork design. The module at this time can only deal with TIN models, however, with the integration of algorithm for solid and parametric modeling technique, its usability will increase. Further studies are in progress to update this Pad based BIM module, incorporating the 4D (time) and 5D (cost) design functions to automate the calculation of time and cost at any particular section. The large scale validity assessment will also be carried out in projects with different cost and duration.

## 6 Acknowledgement

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