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# Construction sites' sustainability enhancement through earthworks optimization using Building Information Modelling



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**Abstract**. Earthworks are the very beginning of every new construction project, if not well designed and controlled, they may cause time and cost overruns and, overall affect the sustainability of the whole project. Industry 4.0 technologies like high-precision positioning GNSS/RTK and Building Information Modelling may help improving earthworks thus reducing waste, reworks, and energy demand. A novel workflow to integrate data coming from multiple sources within a reliable, BIM-based, digital terrain model is proposed. The proposed method allows professionals, as designers and managers, to receive updated and correct data, for better decision making and, thus, for more sustainable construction processes. Side benefits of the proposed process is an improvement in workers' safety. A case study, a quarry in northern Italy, proved the usability of the method.

## 1. Introduction

Climate change and environmental degradation are an existential threat to Europe and the world. To overcome these challenges, the European Commission adopted the Green Deal to transform the EU into a modern resource-efficient and competitive economy [1]. The building and construction sector is one of the key components in the transition to a resource-effective and climate-neutral society. Globally, approximately 100 billion tonnes of waste is caused by construction, renovation and demolition, with about 35% sent to landfills [2]. Geotechnical processes, such as earthworks, ground improvement and foundation construction, are often energy- and resource-intensive. Thus, they play an important role in moving towards more sustainable building construction practices.

The convergence of digitalisation and sustainability is inevitable [3]. Digitalisation provides access to an integrated network of information that can benefit society and businesses. Digital technologies such as Building Information Modelling (BIM), blockchain technology, artificial intelligence and machine learning, big data, internet of things, laser scanning, and drones are being deployed to help deliver better construction and infrastructure projects that could exceed owners' and occupants' satisfaction with fewer carbon footprints. Focusing on earthworks, researches proved that the application of new technologies may help in carbon footprint reduction [4]–[6]. Construction industry can thus address building industry sustainability objectives by various elements, among these: reducing project costs through the application of digital technologies [7], [8]. Earthworks are the very beginning of every new construction project, if not well designed and controlled, they may cause time and cost overruns [9]. Industry 4.0 technologies, such as high-precision positioning GNSS/RTK, in modern heavy earthwork machinery, allow for the collection of a huge amount of data to keep track of the excavation process. BIM is now becoming more and more present in every construction project but most of the time models lack geometric/parametric data of the topographical surfaces [10] and also of the soil characteristics, which can be included and exchanged using IFC 4.3. Enhancing information management during the excavation phase can deliver many cost and time savings [11], as well as increasing the sustainability of this phase of the site by reducing $CO_2$ emissions [12]. A novel workflow to integrate data coming from multiple sources within a reliable, BIM-based, digital terrain model is presented. The proposed workflow establishes a close link between IFC data and the mapped ground surface to be provided to the machine guidance technology to increase productivity and ensure safety in the construction site. New technologies in the earthwork sector allow for reduced rework and higher precision [13], with less resources consumed, while the proposed workflows help in closing the loop between the construction site and the BIM model. A case study proved the robustness of the proposed method although highlighting its sensitivity to systems malfunctions or workers behaviours, that are almost impossible to be avoided on site. Moreover, this work extends the concept of "as built", providing future users of the building and of the BIM model with updated data. The information properly stored in the model and in connected databases can then be used for maintenance and future modifications of the buildings. The proposed method allows professionals, as designers and managers, to receive updated and correct data, for better decision making and, thus, for more sustainable construction processes.

## 2. Optimising earthworks in a BIM environment

Although the main aim of the proposed method is to optimise the excavation process in order to improve economic and environmental sustainability of the first stage of the construction process, the use of digital technologies allow for some important side-products: a) to have an updated topographic surface in the as built BIM model, i.e. the CIM (Construction Information Model – BIM model to be used and updated during the construction process, basis for the eventual development of the AIM – Asset Information Model) to be used in the remaining stages of the construction process; b) to collect the relevant data from the excavation machineries. The latter may result in further optimisations in future works, the former helps in a better data-management in the rest of the construction process (Figure 1).

The earthworks operation (point 2 in Figure 1) must be properly designed in advance (design of cut and fill, definition of machinery, definition of soil characteristics and work planning) and then controlled during the excavation process (monitoring of material moved, cost control, comparison with the design). Point 2 depends on point 1 (site survey), which can be developed using several tools (e.g. UAV, total station with/without GNSS RTK, laser scanner) and also updated using instruments installed on the machines. During the earthworks, the updated data, i.e. the Digital Terrain Model (DTM), are used to update the BIM model (point 3 in Figure 1). The updated surface is available to the download via the cloud application of the producer at any time, that must be saved as a LandXML in the desired folder using the proprietary software. Opening the current project in Revit is possible to recall the script and the updated file using the Dynamo Player function where the nodes that need manual input, (e.g. folder path) are made interactable. This allows to make a comparison between the works planned and those carried out (in terms of position, slope, quantity). The process of updating can be carried out by the BIM modeler who can find the required file on a common database produced by the earthworks contractor. Or can be collected and converted by the work director itself at the end of the day shift, without the need of sending a topographer to the site to perform a survey to obtain an updated model. At the end of the earthworks, the updated model (CIM, point 4 in Figure 1) can be used as an as-built and also for calculating additional indicators (e.g. $m^3$ of rework, comparison with the design, changes made, etc.). More specifically, with the instruments used during the site survey and the sensors installed on the machines, it is possible to have a periodic update of the model (specifically of the Revit Toposurface),

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helping the technicians in the office to check for discrepancies and react in a timely manner. The process, explained in more detail in the following paragraphs, involves additional software and cloud storage; it is complex and therefore needs to be managed with clear steps to achieve an as-built.

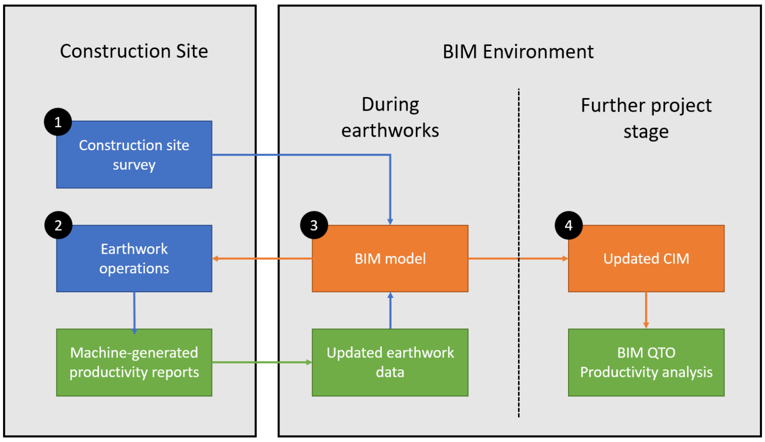


**Figure 1.** Earthwork process in combination with BIM

Point 1 can be performed with the, nowadays common, GNSS survey controllers or, the more precise, laser scanners or drones. Point 2 requires the earthworks machineries to work always "on precision" which means that there should be a RTK correction flux. The system itself should be in mapping mode throughout the process or some data may be missing until the blank areas will be covered again. The precision of the mapped points is between 1,5 and 3 cm thanks to the RTK corrections. There are different criteria in which the points are generated, the one used in this case is "the lowest reached" and it has been seen that the data coming from excavators are not always smooth surfaces since its movements make it more difficult to understand when it is digging or only moving materials. In the next paragraph, the process and procedures to update the BIM model is presented (point 3). How the data are collected from the initial condition (point 1) and from the excavation process (point 2) are not investigated in this paper.

## *2.1. Earthworks optimisation process with BIM*

This process has been developed to be used during the earthworks to keep the model up to date until the end of the works, it involves the use of a script created using Dynamo software and allows data management, import, export and transformation from proprietary software (e.g. Trimble and others) to Autodesk Revit.

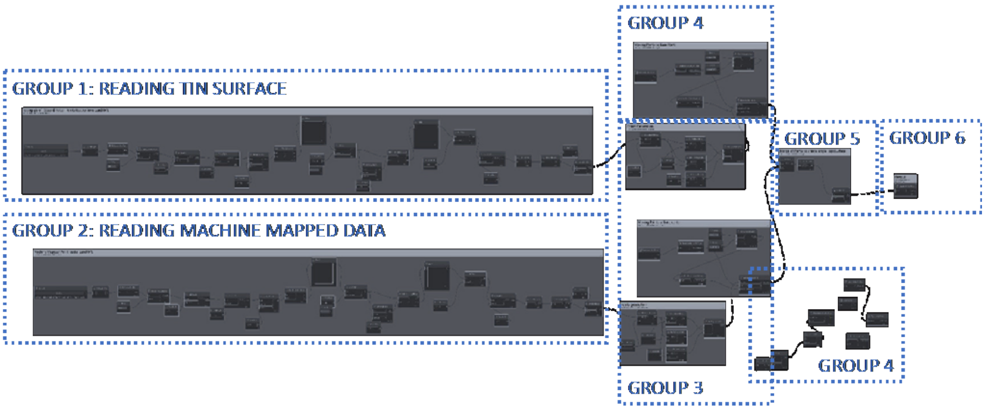


**Figure 2**. Scheme of the script for toposurface update

The script presented is specific to Revit environment, but the managing of the LandXML can be performed in any software that is capable to read such open format. Figure 2 provides a schematic representation of the script to process the data from the initial survey and, subsequently, from the operating machines. The individual steps, realised with Dynamo, are clustered into 6 groups leading from the survey to the surface modelled in Revit. Besides group 6, each group is made of many Dynamo nodes. A brief description of each group follows:

- Group 1 reads the Triangulated Irregular Network (TIN) surface (LandXML) file regarding the initial condition of the site and extracts the coordinates of the vertices.
- Group 2 loads the LandXML file of the mapped points coming from the machine.
- Group 3 translates the numbers obtained from the two surfaces into Cartesian coordinates.
- Group 4 is critical for the correct positioning of the toposurface in the BIM model created by Revit; essentially, the code blocks here have the task of calculating the centre of mass of the toposurface and converting it into the coordinates used by Revit (namely N/S and W/E). This allows automatic positioning of the toposurface and also the correct export of the IFCterrain with the relevant properties (i.e. any IFC exported from the model will be georeferenced).
- Group 5 is used to merge the results from the mapped surface and the as-built surface. The result is a single toposurface that can be imported (group 6) or further processed (e.g. additional simplifications).
- Group 6 Although made of a single node is the crucial part of the whole process; it imports the toposurface into Revit and places it in the centre of the site view. In addition, if the previous surface is retained, it is then possible to calculate the difference in volume.

The use of 3D software allows automatic volume calculation, where the main requirement is to generate a reliable model. By using laser scanning or UAV, the as-built surface can be generated by computer after the survey, which can be compared with the previous condition, this method is also called surface-to-surface method.

## *2.2. The case study*

The case study is a quarry located in the northern area of Italy with a 2D projected surface of 12’2967 $m^2$. Earthworks are made using a CAT 330 excavator equipped with a machine guidance system operating with GNSS/RTK via a Virtual Reference Station (VRS).

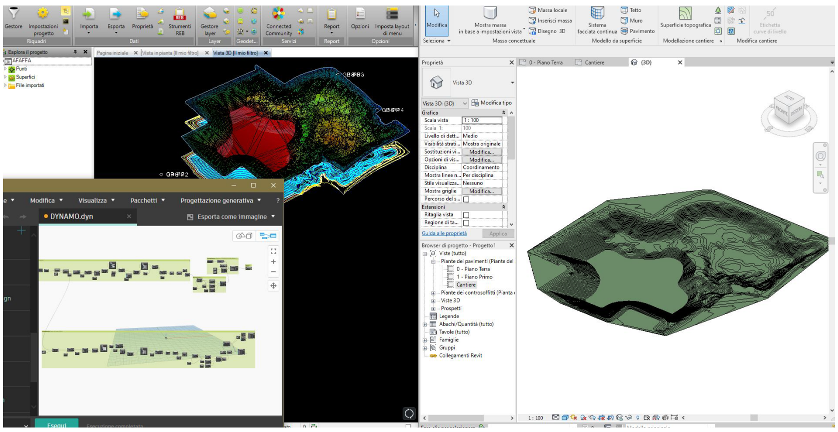

**Figure 3.** Data processing of the case study

As already mentioned above, the whole process starts with the survey of the site. The survey produces the DTM of the initial conditions, in this way the script created to automate the procedure will use automatic harvesting data to calculate the work done by simply doing a Boolean subtraction. The format of such a surface should be compatible with the software used for the calculation or in the interoperable LandXML format. The mapped surface is then converted into a LandXML format using the proprietary

CAD software. The procedure of retrieving data from the cloud can be done at any stage of the work since the machine will keep uploading the recordings. To automatize the merging of the as built data to the surface of the initial condition, the dynamo script described in the previous paragraph has been used (Figure 3). The script has been tested with two mapped surfaces taken respectively in May 10$^{th}$ and May 26$^{th}$ 2022 that comprehend 13 working days. The frequency of model updating can be decided during the design phase according to the forecast production, the WBS (for concurrent works) and whenever the safety coordinator, the work director or the designers think there is the need (or a planned) of a model check.

The process of DTM gathering and update worked with no issues in the case study and also showed during the excavation process the areas worked (cut and fill), while helping the operators of the machineries in avoiding reworking of areas, leading to less usage of fuel, and so less emissions (and costs and working hours). The benefit of less reworks is given by the usage of the 3D GNSS system itself, that is capable to provide guidance and bucket automatism staying within the precision of 1,5 cm to 3 cm. Also, by checking the area covered the whole design team can forecast corrections to the design and send in real time the updated model to the machine operator. As can be guessed such machine technology is fundamental for creating the mapped data. Having a better understanding of the work performed, avoiding the stacking of the areas and having a precise guidance allows to plan more carefully the overall working schedule of the construction site and speed up the production leading so to less consumption of fuel thus having less carbon emissions. Further studies should be conducted, but the greater accuracy provided by the sensors on the machineries, in addition to the possibility of having direct feedback on the works in the office, help in reducing the quantity of soil reworked.

## 3. Conclusions

Sustainability of the built environment is an issue that needs to be addressed at all stages of a project's lifecycle. The construction phase must be included in any kind of sustainability assessment of a project. From this perspective, excavation works should be analysed for their potential contribution to improving the sustainability of each project. They can make a significant contribution to improving economic and environmental sustainability. For example, they can help to reduce $CO_2$ emissions from the fuel consumption of excavation and material transport vehicles. This paper presents a method that uses some digital tools recently adopted by the construction sector to improve the design and execution of earthworks. The proposed method links the data collected from the preliminary survey in the field to a BIM model that is first used to plan the excavations and is then updated with the data retrieved from the earth-moving machines, in the case study an excavator. There have been discovered several limitations that requires more technical and logical optimization, The mapped points generated by the excavator have the tendency to create cones on the surface, this is caused by the fact that the movement of the arm is complicated rather than for a dozer that works mainly on planes. The mapped toposurface must be assignable to certain areas of the project where it is forecasted certain excavations, according to either the SBS (Space breakdown structure) and WBS (Works breakdown structure), this to create specific QTO analysis. To map correctly on a site, it is required to have constant RTK corrections and is preferable to have all the machine equipped with such technology otherwise not all the soil moved will be registered. The IFC 4.3 schema must be furthermore studied to understand which other kind of elements can be represented by the entities. The lack of an API system for the retrieval of the surface is slowing down the process.

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