BIM 3967

5D planning in earthworks mining constructions in hilly topography

Axel Franco Castro Cuadra, Franco Manuel Sánchez Romero, Julio Cesar Velasco Alvarez, Christian Chinchay Rios

Abstract

As BIM methodology has been mostly implemented in the construction industry, certain areas such as surface mining have been neglected. Mining projects are generally large and often located in hilly landforms; consequently, critical activities included in the construction schedule may have a high risk and cost impact.

The aim of this research is to implement BIM in a mining project for collaborative works through 3D, 4D and 5D modeling to ensure the adoption of the best work practices in project planning, improving constructability and reducing risks, as well as to achieve an adequate cost control during the development of the project. Regarding planning, a detailed description of the division of the activities to ensure continuous operation and the sectioning of the project, considering the hilly topography of the area, is provided. The work method for project modeling is also explained and the issues found at this stage are presented. Based on the results significant benefits were achieved using 5D modeling, including a better visualization of the design, thus ensuring appropriate constructability and cost control.

Table of Contents

Introduction

Construction industry constitutes one of the cornerstones of Peru's economic growth. As such, construction management poses a challenge in project management efforts to achieve optimal results in terms of quality, execution time and budget. Common problems in the development of engineering projects include the incompatibility of drawings, inadequate design, and engineering documentation, lack of coordination between those responsible for each specialty, and use of outdated constructability pillars in the design. All these errors have a negative impact on quality, productivity, costs, and schedule. [1]

Currently there are different methodologies in the construction sector that guarantee advantages in the different stages of a project from design, construction, and operation. One of the most implemented in recent years is Building Information Modeling (BIM), which has become increasingly popular in the construction industry as it provides multiple benefits, including improved coordination between different specialties, adequate time and cost management, improved constructability, and fewer interruptions during construction, inter alia. BIM methodology creates intelligent 3D deliverables that provide practitioners with the visualization and tools to efficiently plan, design, construct and manage building and infrastructure. Yet, BIM has been developed and implemented mostly in the field of urban and industrial infrastructure and has not experienced the same growth in large earthmoving projects.

On the other hand, proper time management is essential for the success of a project, otherwise it could lead to higher costs, construction process disruptions and, possible stoppage and decommission of the project, due to great economic impact in some cases.

Given the above, our research focuses on the implementation of BIM methodology to present the resulting benefits, specifically, in the correct planning of a project and the improvement of constructability in the execution of a mining project where terrain conditions are abrupt.

Theoretical Framework

BIM Methodology

Building Information Modeling (BIM) is a collaborative-work methodology designed to manage data-based models, created by the stakeholders of a project, in the pre-design, design, construction, operation and maintenance stages of the infrastructure. As there is no standard BIM methodology for all types of projects, it changes according to the specific characteristics and requirements of the project. [2]

Planning

Project planning refers to the establishment of a set of instructions in sufficient detail to convey to the project team exactly what needs to be done, when it needs to be done, and what resources to use to successfully produce the project deliverables. The project manager is responsible for planning and must ensure that the project is executed correctly and to the complete satisfaction of all relevant stakeholders. The main advantages of adequate project planning are as follows:

- Eliminate or reduce uncertainty.
- Improve operational efficiency.
- Gain a better understanding of the project objectives.
- Provide a baseline for monitoring and controlling the operation. [3]

Constructability

The Construction Industry Institute (CII) defines constructability as the optimal use of construction knowledge and experience in planning, design, procurement, and management of construction operations. [4]
This methodology allows for optimal progress and integration of construction knowledge and experience in construction project management. The ICC has prepared a handbook that identifies twelve principles of constructability to be applied over the project life cycle [5]. These are as follows:

- Integration. Constructability must be made an integral part of the project.
- Construction expertise. Project planning must involve construction expertise and qualification.
- Expert team. Composition of the team must be appropriate for the project.
- Common objectives. Constructability enhances when the project team gains an understanding of the client's and project objectives.
- Available resources. The technology of the design solution must be matched with the resources available.
- External factors. External factors can affect the cost and/or program of the project.
- Program. The overall program of the project must be realistic, construction-sensitive and have the commitment of the project team.
- Construction methodology. Project design must consider the construction methodology to be adopted.
- Accessibility. Constructability will be enhanced if the construction accessibility is considered in the design and construction stages.
- Specifications. Constructability is enhanced when construction efficiency is considered in the specification along its development.
- Construction innovation. The use of innovative techniques will enhance constructability.
- Feedback. Constructability can be enhanced if a post-construction analysis is undertaken by the project team.

Objective

The objective of this research is to implement 3D, 4D and 5D BIM methodologies in large earthmoving projects to analyze the benefits obtained in this case study, characterized by hilly topography.

Procedure

For this research, BIM methodology implementation started reviewing data obtained through 2D drawings in DWG format, from civil design, hydraulics, mechanics, structures, and geotechnical monitoring instrumentation disciplines. The 3D modeling was then performed at LOD 300 using Autodesk's Revit and Civil 3D software packages. These tools provide quantities for the different items involved, budgeting, and so be able to start the project baseline schedule via planning software.

Once the 3D model was obtained according to the construction process, the analysis of interferences and inconsistencies found in the information received was performed.
Following the resolution of interferences, a more detailed analysis of the schedule was conducted to prepare the master plan. Navisworks software was used to combine the 3D model and the schedule to obtain a 4D model, which shows a preliminary view of the construction process. Subsequent meetings held between the different specialties and the construction team provided an opportunity for improvement, such as the elimination of interferences that could arise during the construction process. Costs were then added from the CAPEX estimation of the project to obtain the 5D model. Figure 1 depicts the workflow proposed.

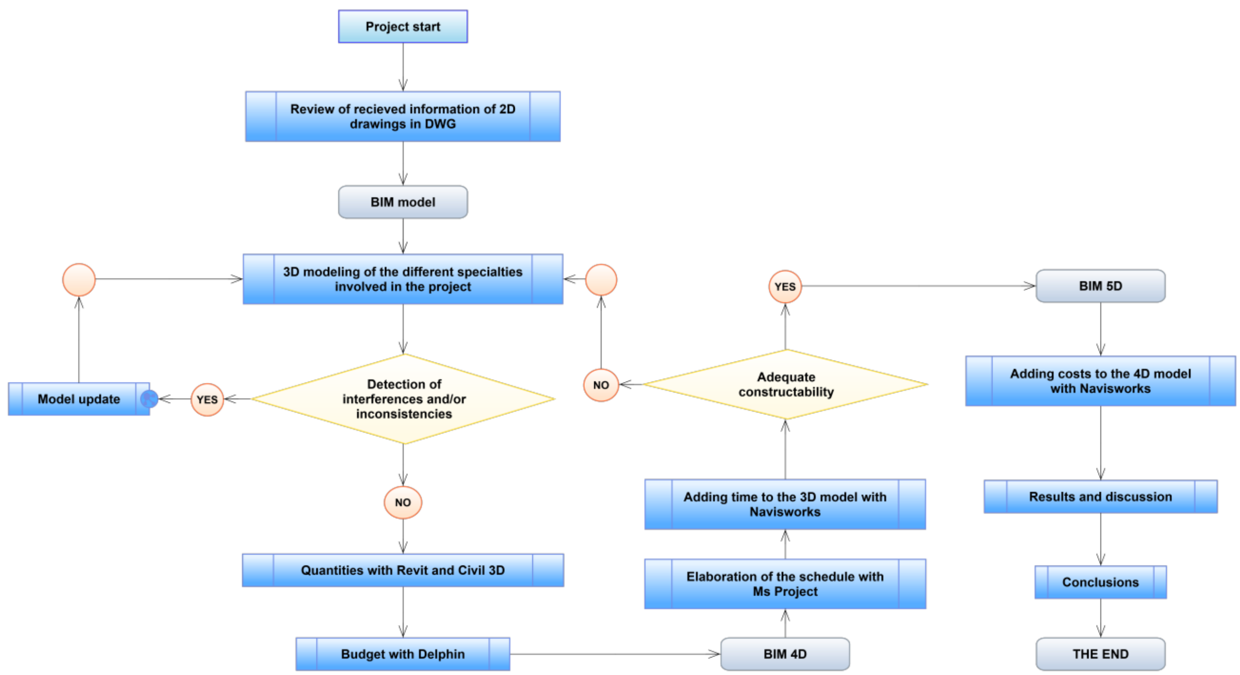

Figure 1 - Work flow

Case Study

Project Description

The case study is a tailings storage facility (TSF), located in the Andes of Peru at an approximate altitude of 4 600 masl, currently operating at its Phase 4. The scope of the project includes the raising of the central axis of the TSF by 5.8 m, its Phase 5, aiming to increase its capacity and, therefore, its operating life. For this raising, construction of the dam, surface drainage management through hydraulic structures, construction of the reservoir by building the perimeter access road, geotextile-, GCL- and geomembrane-composed liner system installation, installation of tailings lines for dam operation, and geotechnical instrumentation installation for monitoring and surveillance of the TSF, have been considered. Figure 2 depicts the project plan view.

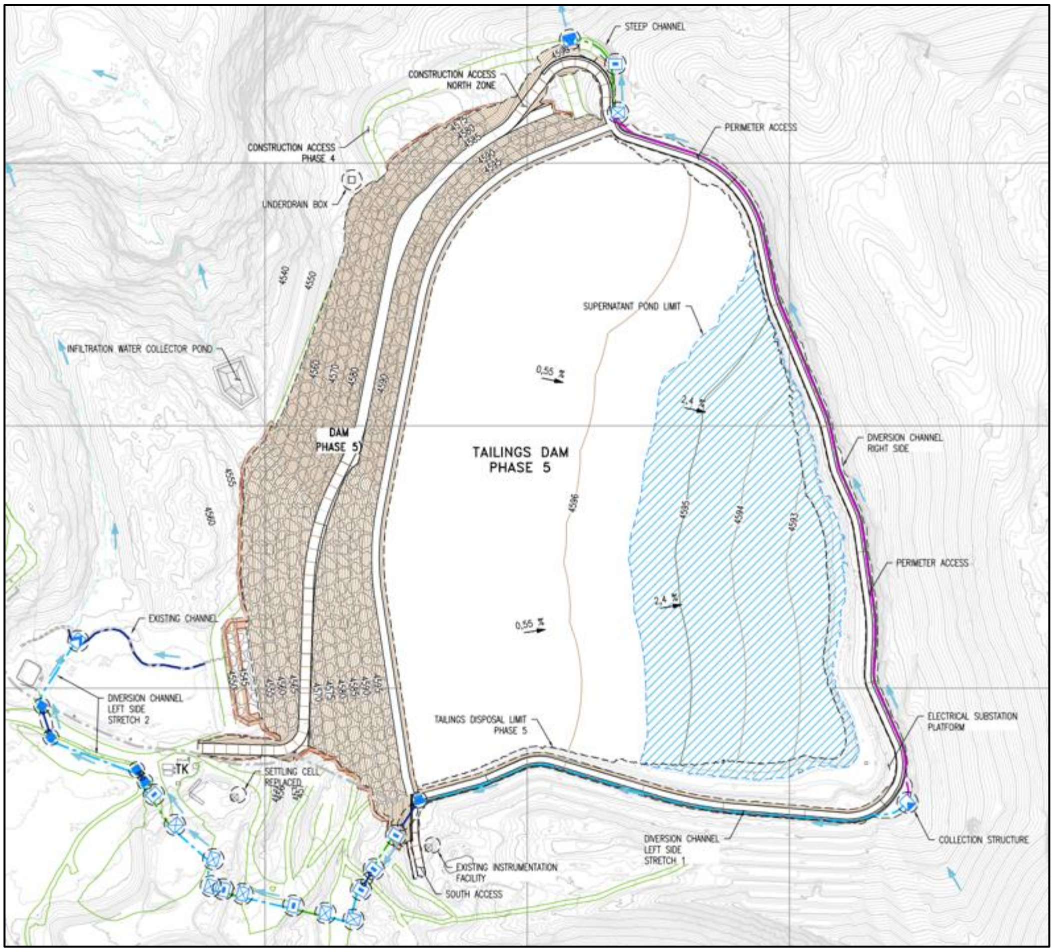

Figure 2 - Phase 5 TSF raising - Plan view

BIM

To implement and use BIM in this type of project, work was performed at a maturity level 2, facilitating the transfer of files in a common format and the interaction between specialists. Also, consistent with the BIM execution plan (BEP) developed for this project, BIM LOD-300 was used, as it ensures the shape, size, orientation, location, quantity, and handling of the information accompanying the model. [6]

It was decided to work with software from Autodesk. Civil 3D was used for the earthmoving civil design to create surfaces and solids for the tailings dam raising, whereas Civil 3D and Revit were used for the modeling of hydraulic structures by creating a family library for the 3D modeling. Regarding geotechnical monitoring instrumentation, various instruments including accelerographs, survey control prisms, and piezometers were modeled in Revit, as well as for other concrete structures. Nevertheless, there were some complications and delays in the modeling of the pipelines, as they follow an alignment with inclination angles due to the HDPE pipe properties. Therefore, Civil 3D was used for solids generation, and properties were added using the property sets tool. Figure 3 depicts the layout of the modelling project.

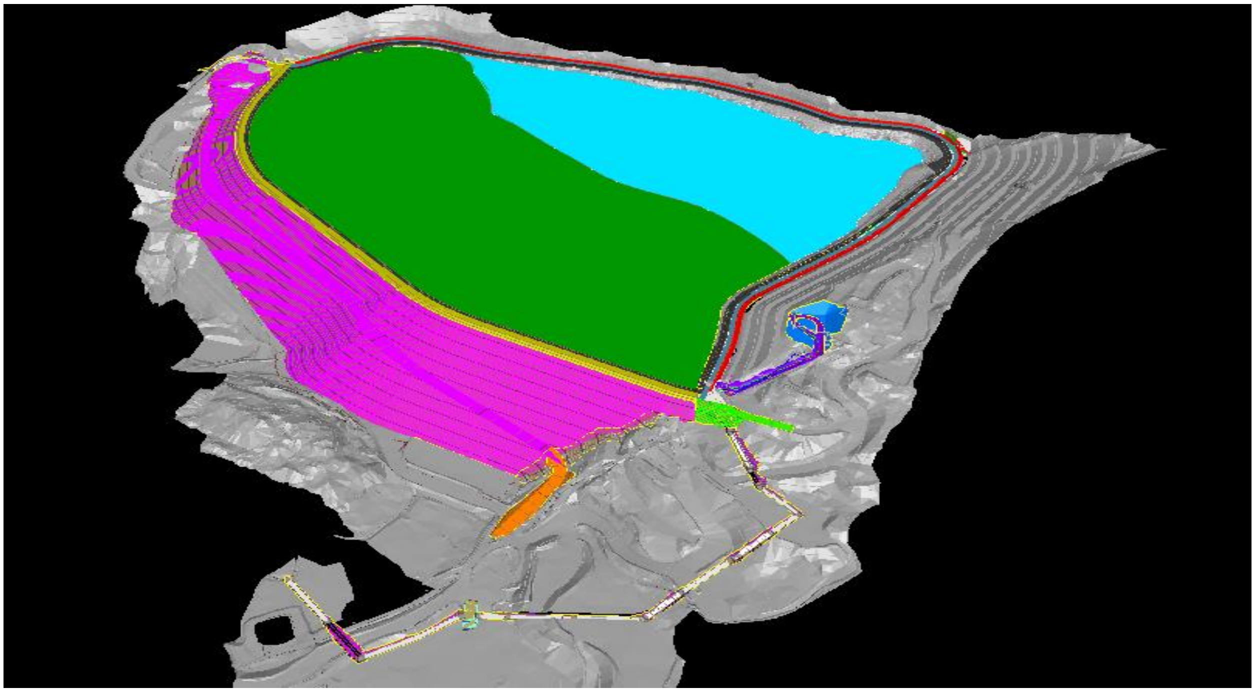

Figure 3 - BIM model layout - Plan view

After modeling, inconsistencies found in the engineering drawings and in the updated model of the topographic surface and its details were analyzed. Also, interferences found in the different specialties, which arose in the development process due to the late and non-referenced elaboration of some specialties during the engineering development, were analyzed on the basis of significance. Lastly, based on an interference report and the coordination of the specialists, an assessment of the changes to be made is performed in accordance with the scope and importance of the project so as to eliminate interferences and inconsistencies.

Time Management

Planning is fundamental for construction because it defines the work sequence, ensuring an adequate work rhythm. However, unlike urban construction where a process of sectioning, division into work fronts and work rhythm are already defined, other variables have an impact on this type of construction project. There are two aspects that have the greatest impact and are specific to mining projects. The first one is location. Most mining operations are located in the Andes of Peru, where topography represents a problem due to its abruptness, complicating the project from its conceptualization to engineering development, construction, and planning. As for the second aspect, unlike other construction projects, there are usually few operational stoppages in mining; therefore, in the planning stage, it is essential to consider the fact that operation in a mining unit is continuous.

In view of the above, the project was divided into 3 sub-stages to avoid impacting the operation. These consisted of a first stage of raising of 2 m, referred to as 5A; a second stage of 2 m, referred to as 5B; and a last raising of 1.8 m, referred to as 5C. Subsequently, sectioning of the sub-stages was conducted. For this purpose, the criterion used was the one that, as a whole, includes the recommendations of the specialties involved in the engineering and the level of scope of the work to be conducted. Such sectioning differs from those commonly generated, where division is made to balance the amount of labor. However, in the case of some sectors, such as hydraulic works, the balance was made according to the amount of labor to be executed and, subsequently, the activity train was generated. Figure 4 depicts the sectorization performed using the stated criteria.

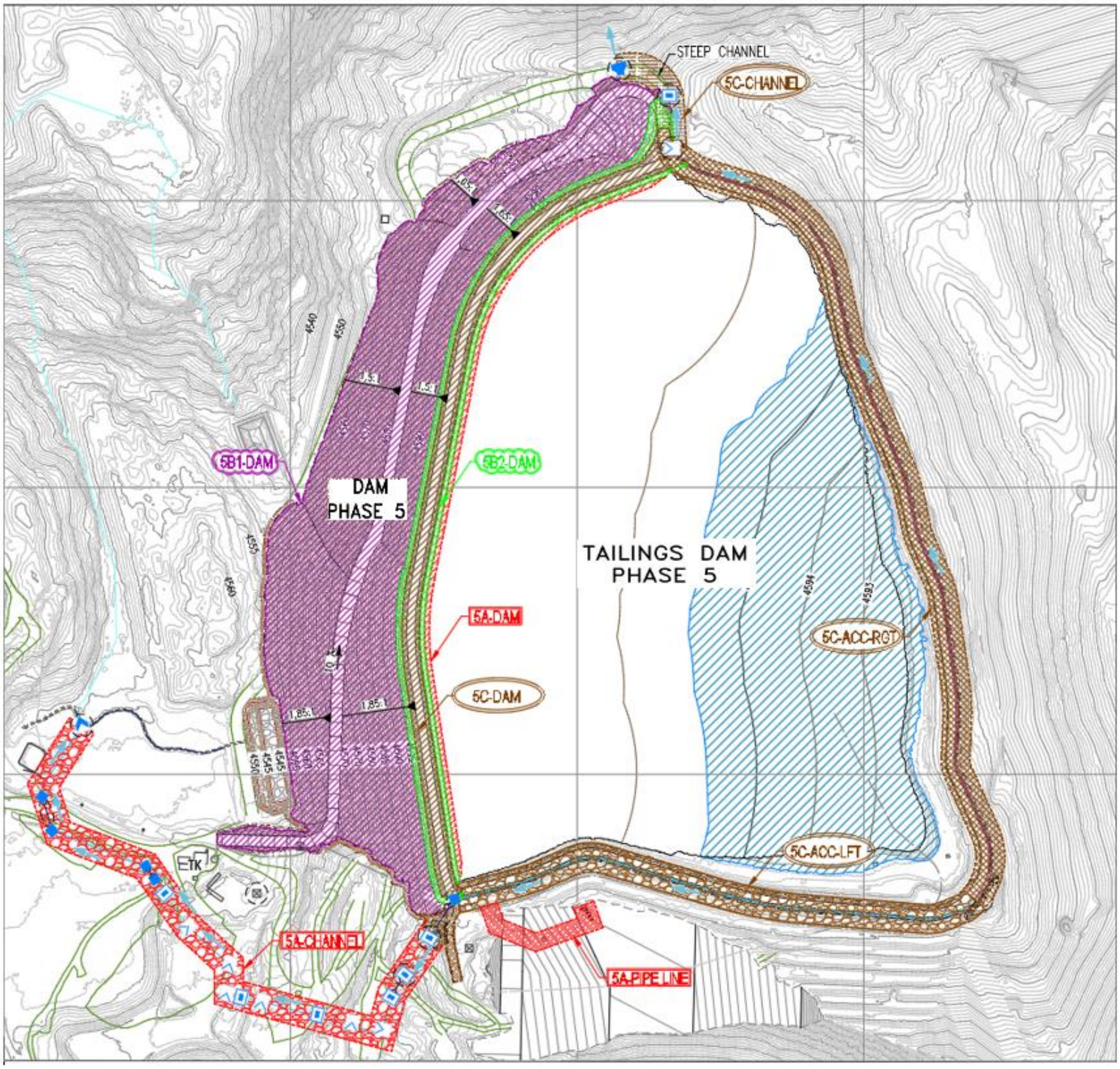

Figure 4 – Plan view - Sectioning of the project

Due to the size of sector 5B1-DAM and in order to improve constructability, it was deemed convenient to generate two fronts and optimize time. A cross section of the dam is depicted in Figure 5. However, the hilly topography prevents the development of two fronts. For this reason, a temporary access road located at the toe of the dam was designed to accommodate two work crews, in addition to projecting work during day and night shifts to drastically reduce the time required. An economic assessment of this option was also conducted, which proved to be technically and economically feasible. Figure 6 depicts the projection of the temporary access road and the two work fronts that could be generated for this sector. Based on all the criteria and conditions mentioned above, the master plan was created using Primavera P6.

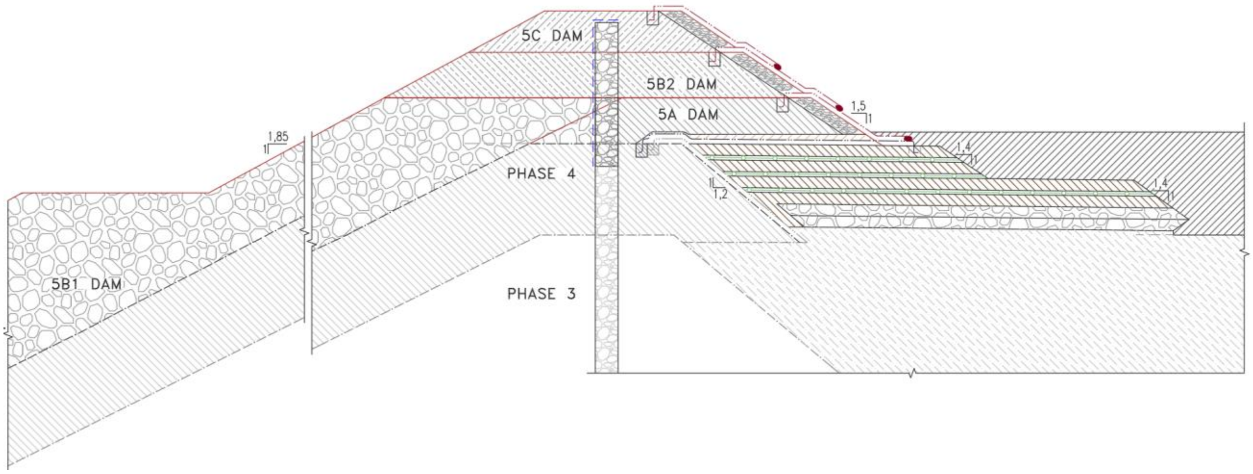

Figure 5 – Section view – Sectors and subsectors

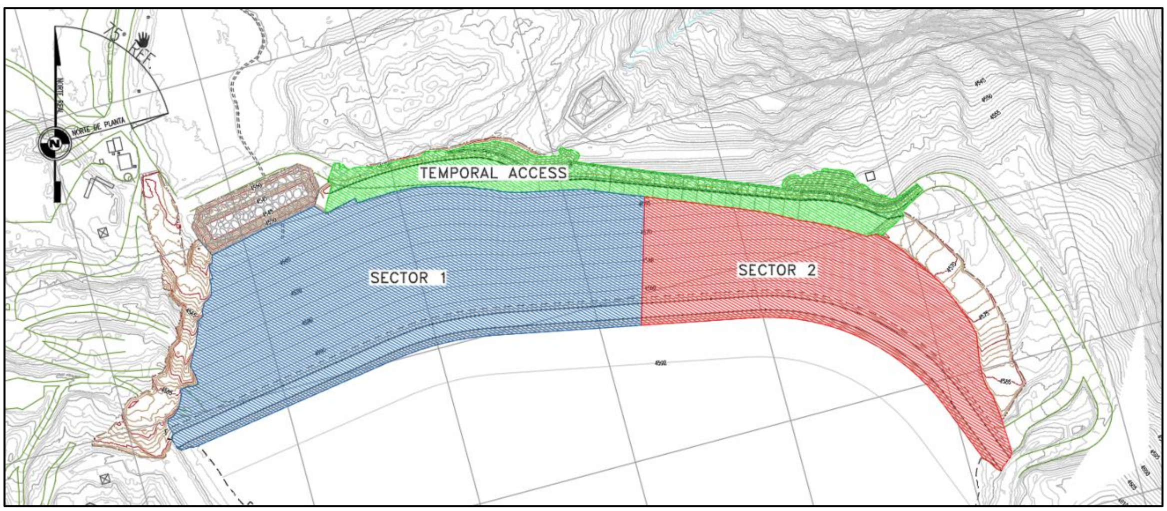

Figure 6 – Plan view – Temporary Access Road along two sectors or subsectors in 5B1-Dam

Cost Management

The cost management included in the BIM methodology enables reaching the 5D. Once interferences have been resolved, by means of adequate constructability and planning, the cost is estimated. Delphin Express software was used to calculate the budget, adding information on the unit price analysis of each activity of the work breakdown structure (WBS), including all the resources that comprise it such as labor, materials, construction equipment and subcontracts.

Results

3D BIM

Although all the modeling was completed, modelling specialties such as pipelines is complicated. After integrating the model, the specialties with greater involvement and importance were analyzed. The analysis of the civil and hydraulic design specialties was conducted using the software function called "Clash detective", which compares two types of elements, or models, with each other. The analysis was conducted, and the elements were identified according to their level of severity. Interferences were corrected on the basis of the relevance of the specialty and operability for the project. Table 1 summarizes the number of interferences that may affect the construction process; however, no interferences were found in the specialties of piping and structures due to the limited scope of the project under study.

Specialty		Number of interferences
Civil design	Hydraulics	4
Civil design	Pipelines	3
Civil design	Geotechnical instrumentation	6
Civil design	Existing infrastructure	6
Hydraulics	Pipelines	1
Hydraulics	Existing infrastructure	5
Mechanics	Existing infrastructure	2

Table 1 – Number of project interferences

During the 3D modeling using the data collected in 2D and updated in the field, inconsistencies, incompatibilities, and lack of information were found in the different specialties. Among the most significant were variations in dimensioning, different schemes for the same instrument due to a lack of coordination between specialties, lack of information on structures not projected or not included in the topographic survey used in design, and incongruence between the drawings and the engineering documentation. Most inconsistencies are due to the incorporation of fast-track engineering studies. Table 2 summarizes the number of the main incompatibilities found in all specialties.

Specialty	Number of inconsistencies
Civil design	22
Hydraulics	12
Pipelines	5
Geotechnical instrumentation	10

Table 2 – Number of project incompatibilities/inconsistencies

4D BIM

Upon rectifying the interferences and incompatibilities, the above-mentioned sectioning was followed by the development of the master plan in Primavera P6, depicted in Figure 7. Figure 8 shows the incorporation of the schedule into Navisworks software.

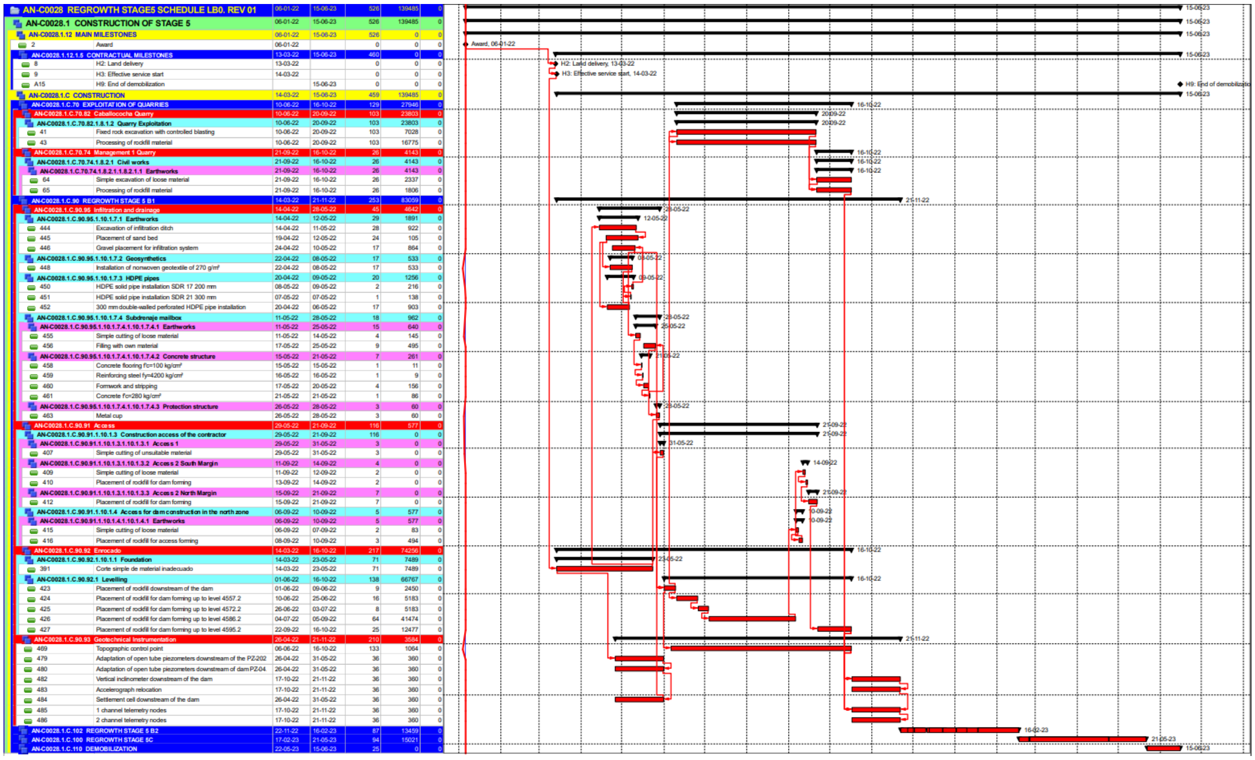

Figure 7 – Schedule developed using Primavera P6

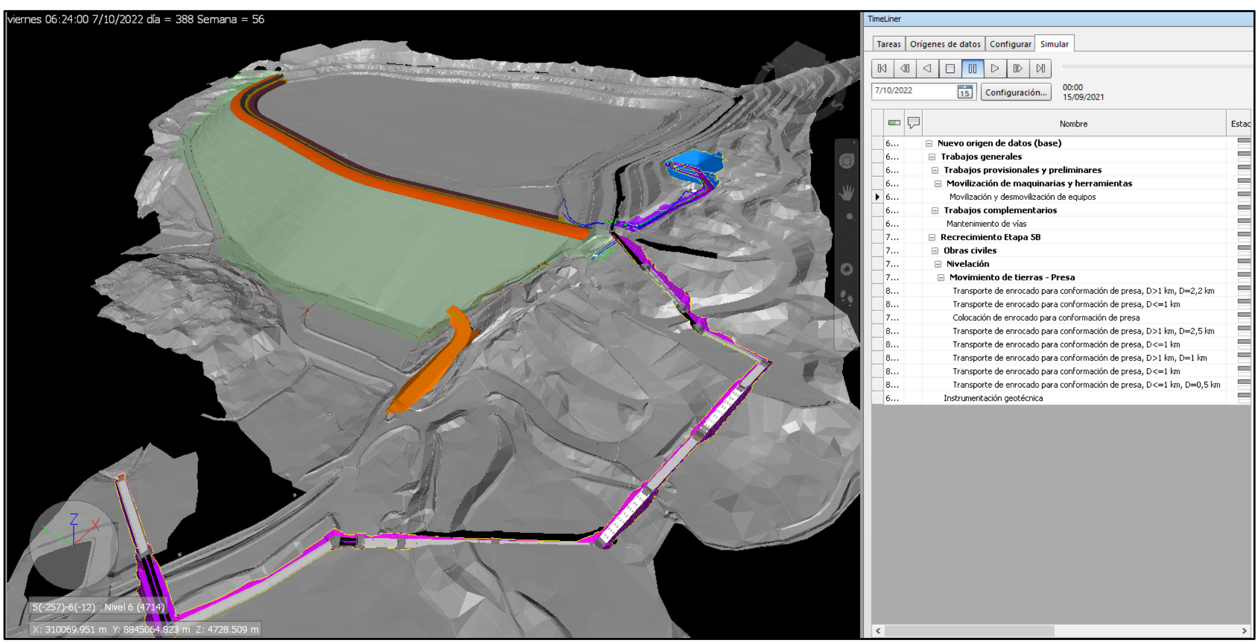

Figure 8 – 4D BIM developed

5D BIM

Subsequently, the budget is incorporated into Navisworks software, where a simulation of the construction of the project including all the specialties mentioned above was performed. Thus, the execution time, the activities with their percentage of progress and the accumulated cost up to the simulated date can be visualized.

Among the advantages of 5D BIM for cost control using Navisworks software, is that, once this level is reached, it allows quantifying the actual progress made up to a certain date, representing a great advantage for valuations. The 5D simulation allows those involved in the project to better manage costs during construction, to observe the impact of changes and to compare reality versus projections. Furthermore, 5D modeling allows us to visualize when and where the budget will be affected, which is fundamental for project control.

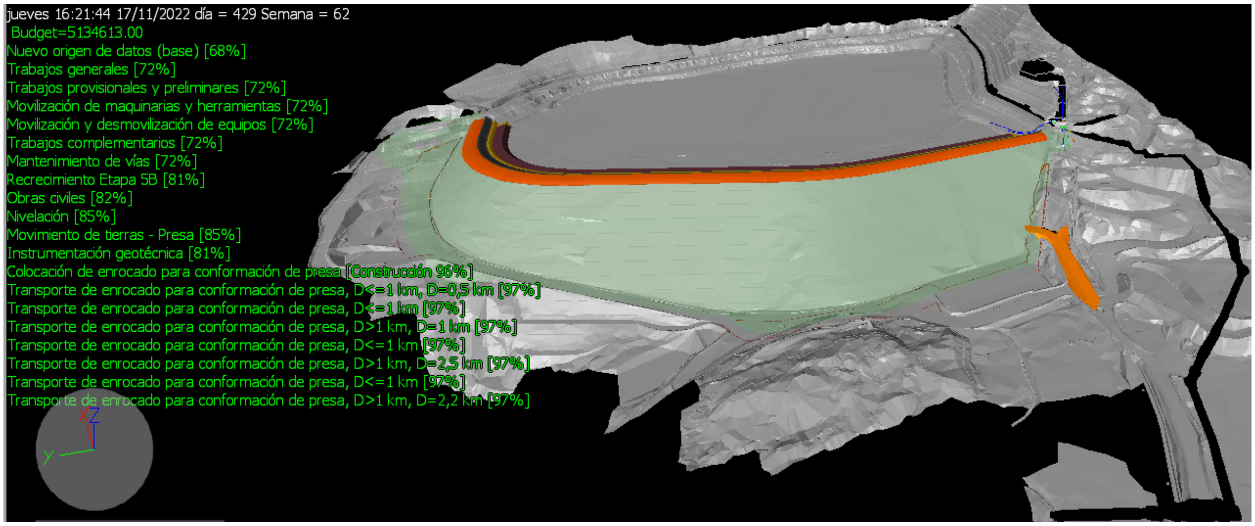

Figure 9 - 5D Simulation - sector 5A end of construction- Dam

Based on previous research, 2D project development is rapidly becoming outdated, being the new trend to develop projects with more details in more dimensions. [7] For instance, 3D-BIM provides a wide advantage because the visualization provides a simpler and more adaptable vision of the project, saves time, allows for adequate communication between the work team and a quicker understanding for the next stage i.e., construction. It is evident from the results of this case study that there is interference with the existing infrastructure, as some crossings with canals, pipelines and existing infrastructure were not included in the topographic information of the project.

Interferences and incompatibilities of different specialties were identified in this case study, all of which were successfully addressed by the project team. Also, it was possible to implement the 4D model, ensuring the adequate constructability of the project by observing or conceptualizing the modeling of the construction process. Thus, it was possible to ensure an adequate Master Plan and, consequently, generate work fronts, ensuring their continuity. The 5D implementation also made it possible to observe the evolution of the budget and to have a better control of the construction process.

Conclusions

Undertaking this study in large-scale projects has been a complex challenge due to the limited implementation of BIM in this type of large earthmoving projects. The integration of different specialties, however, proved to be of great advantage for the specialists. For instance, implementation of 4D-BIM provided a better vision of the design, better adapting the engineering to the real topographic contour lines, ensuring adequate constructability, while the implementation of 5D-BIM provided adequate control of the cost and its development over the projected time.
As it concerns a mining project of great difficulty with a major focus on earthmoving, and as there is no extensive literature on the implementation of BIM in such projects, this research will contribute to BIM implementations in similar projects.

The development of the research provided a holistic view of the project, allowing specialists to make decisions together, determine priorities, solve interferences and incompatibilities, ensure proper construction and operation of the project, and avoid a large number of RFI's that could be generated by the builder. Additionally, change management is much easier and faster, significantly differing from 2D development and avoiding possible rework. The modeling was complex for certain specialties, being the one related to the HDPE pipes part of the most complicated ones as only 3D models were developed with little information available, and the changes management for this specialty was not so dynamic. Regarding other specialties, it was necessary to invest time for the creation of assets of the organization's processes such as templates, families, among others. It is important to note that when a model is closer to reality, great advantages are obtained. For instance, communication between the various parties involved in the project is enhanced, leading to a faster and better understanding while avoiding the need to invest much time in the reading of drawings or 2D models.

The proper data management will prevent some interferences during construction of further dam raising. Adequate and accurate information on the existing situation is therefore extremely important; topographic survey should be as close to reality as possible.

The implementation of BIM provides significantly more benefits than those obtained in previous projects, including automation of document generation, automation of quantity estimating and budgeting, interaction with construction methodologies such as Lean, control of cost and time management for the supervision team, among others.

It is important to continue implementing these methodologies and to experiment with different tools available on the market for the implementation of 4D BIM, such as Vico Office and Synchro, and Vico Office, Cypecad and Archimedes, among others, for 5D BIM.

Implementation of BIM methodology is advisable to assess the constructability of a project construction planning, as it achieves satisfactory results by including engineering measures graphically identified in a 5D model. It was possible to validate decisions such as the definition of stages and sub-stages of the project construction, sectioning of the work fronts, definition of work crews and shifts, and the establishment of a new access road in a BIM model.

References

[1] Vásquez, J., El Lean Design y su aplicación a los proyectos de edificación, Lima, Perú: Pontificia Universidad Catolica del Perú, 2006.

[2] Sacks, R., Eastman, C., Lee, G. and Teicholz, P., "BIM Handbook: A Guide to Building Information Modeling for Owners Designers, Engineers, Contractors, and Facility Managers," Hoboken, NJ, USA, 3rd ed.; John Wiley & Sons, 2018, pp. p. 688. ISBN 978-1-119-28755-1.

[3] Zwikael, O., "Critical planning processes in construction projects," Construction Innovation, 2009, pp. Vol. 9 No. 4, pp.372-387.

[4] Construction Industry Institute, "Constructability A Premier," CII University of Texas , 1986.

[5] McGeorge, D. and Zou, P., "Construction Management New Directions," Londres, Blackbell ScienckK, 1997.

[6] Khan, A., Ghadg, A. and Nagrale, P., Evaluating Benefits of Building Information Modelling (BIM) Using A 5D Model for Construction Project, 2018.

[7] Martínez, A., BIM y las repercursiones en la calidad de los procesos constructivos, Barcelona, España, 2015.