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Parametric mine design applied to block caving

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ABSTRACT

Underground mine design is generally an iterative and manual process that regularly requires updates as new assumptions and technical considerations become available. Traditionally, these changes can take weeks or months of design hours for the long-term planning team, affecting the timeframe of the entire process and limiting the ability to study various design alternatives. Because of timeframe limits and the need for more ability to effectively analyze different designs, often a mine will result in a sub-optimal design, decreasing the overall long-term profitability and may lead to additional operational challenges moving forward.

Technology in Parametric Engineering and Design is widely used in Civil, Aviation and Manufacturing industries. This technology was introduced to mining applications to automate and accelerate the underground design process, since in parametric Engineering all design items are parametrically linked; it means that any change in a parameter leads to the automatic update, this option allow controlling the parametric model to create the mine design, outputting design centerlines and 3D tunnel shapes. Due to the parametric nature of the model process and templates, this allows for rapid scenario simulation and analysis of multiple alternatives.

This paper examines the application of Parametric Design in a Block caving layout by changing critical parameters at the extraction level, such as tunnel and drawbell spacing, orebody offsets and how these adjustments has been automatically transferred to other levels like undercut. Additionally, these changes has been measured based on the redistribution of the draw points by calculating ore recovery, dilution, pillar size and draw point interaction.

1 INTRODUCTION

Designing underground mines is a complex task that requires attention to detail. It starts with understanding the ore body and creating a mine plan based on the mining method, mine sequence, and production capacity. Mine infrastructure must be designed precisely, including systems for handling ore and waste material, ventilation, and electrical/mechanical systems to ensure success and profitability.

The traditional mine design uses lines and points connecting different parts of the design to create a set of solids to represent a 3D model by extruding a specific section to centerlines. This process has the following challenges:

- Manual and time-consuming initial design pass with traditional CAD/line work design tools.
- Significant iterations required due to multitude of potential paths/designs must be considered.
- Constantly evolving production locations require frequent update to the development design.
- It is not simple to compare designs created and precisely analyze the results since the design process is normally disconnected from the following stages like Mine Planning.

2 PARAMETRIC MINE DESIGN

2.1 Parametric Design introduction

This technology was introduced to mining applications to automate and accelerate the underground design process by defining multiple parameters routinely employed within the mine design process. Figures 1 and 2 describe examples of Parametric Design utilized in other industries.

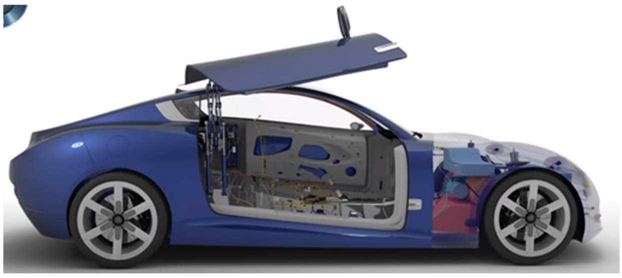

Figure 1 Parametric design used in car design.

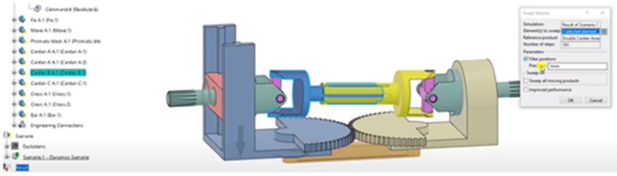

Figure 2 Parametric design utilized in Manufacture.

2.2 Parametric Design applied in mining

Parametric design is a model-based design that incorporates traditional CAD but employs templates to automate mine design. It is a living model created where changes in a localized area update the global mine design. This allows for the quick analysis of different design criteria based on inputs and parameters and, most importantly, reduces design cycle time from weeks/months to minutes/hours.

This technology was successfully implemented in mining using the following steps:

- Import and validate geological solids or production areas
- Build Parametric Model
- Generate Parametric Design Network

2.2.1 Validate and import geological solids or production areas

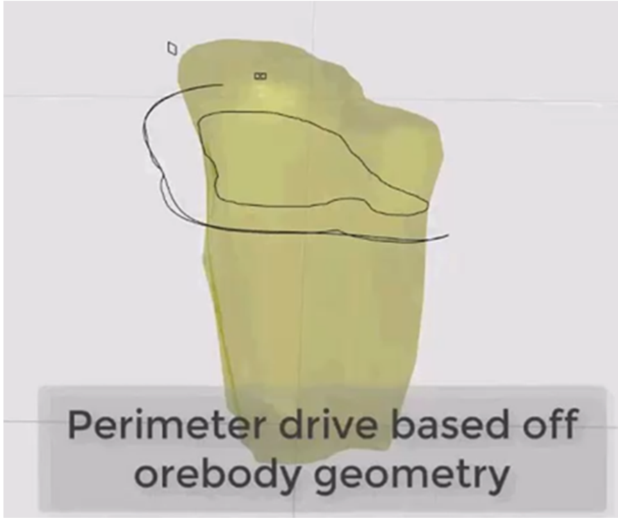

Figure 3 Examples of geological solid imported.

In this step, it is possible to import geological solids or production areas that could be used as a reference or constraint during the design process, such as limiting the extraction zone for tunnel production, geotechnical constraint, location of access, etc. Figure 3 shows an example of an ore body to be designed as a sub-level cave mine; it represents the design's maximum vertical and horizontal extension. In this case, it was used to generate a perimeter for the tunnel access of the first level based on the shape of the orebody; this procedure will be utilized for the design of the levels below, which means depending on the level spacing, the perimeter drive will be adjusted to the ore body shape automatically.

2.2.2 Build Parametric Model

The parametric model uses templates with specific characteristics to control inputs or elements associated with the design, for example, level infrastructure (tunnel width & height, gradient, corner radius, rim drive offset) and ramp design, gradient, radius, width, etc.). Other elements associated with a specific underground method could be defined as well; for example, for Sub Level Caving, ring design could be created automatically by utilizing inputs such as Ring Burden, Number of Levels, Tunnel and Level Spacing (see Figure 4).

Figure 4 **Templates for parametric model.**

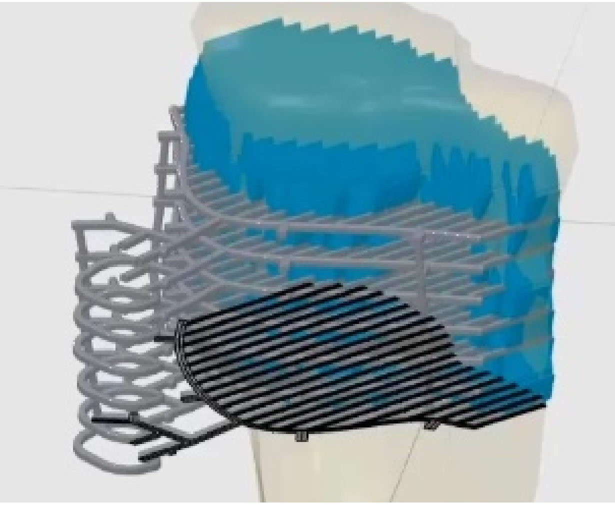

Figure 5 **SLC example of Parametric Design Network.**

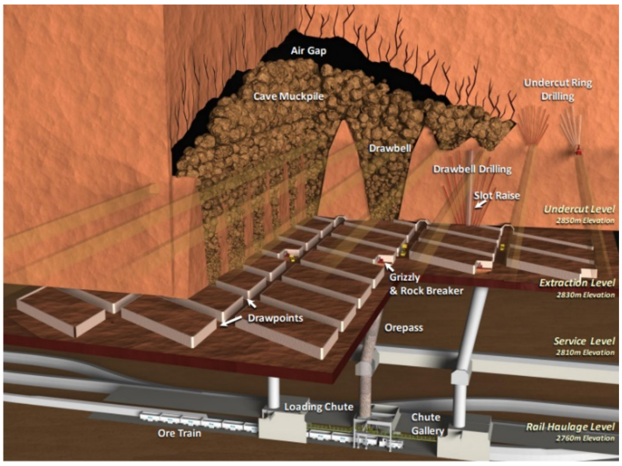

Figure 6 **Block cave development diagram (Mining Journal, 2020).**

2.2.3 Generate Parametric Design Network

In this step, templates created before are based on design criteria to generate the entire design. Changes could be applied in a template or specific inputs to update the design. Figure 5 shows an example used for Sub Level Caving by adding one additional level in the bottom and maintaining all design criteria applied in levels above.

3 PARAMETRIC DESIGN APPLIED TO BLOCK CAVING

Block Cave (BC) is a elaborate underground mine design that connects many elements. Figure 6 illustrates a block cave development diagram where it is possible to see the combination of several levels connected to allow production from draw points. The infrastructure depends mainly on the location of draw points from the extraction level; therefore, ore passes, loading chutes, ventilation raises, and the characteristics of undercut, service and haulage levels depend on the connection with tunnels at the extraction level and then any change applied in tunnels or draw bells is affecting the entire design.

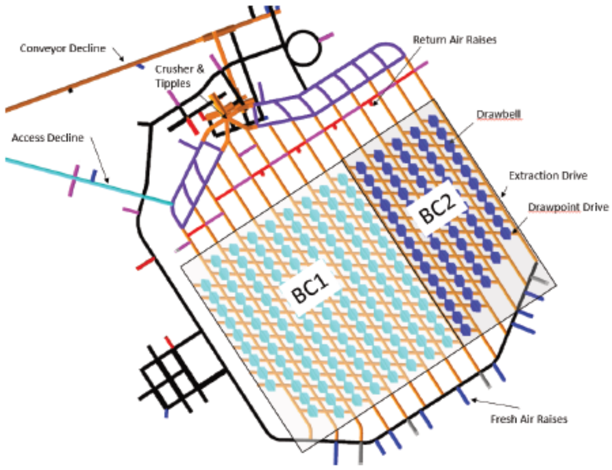

Figure 7 **Carrapateena proposed extraction level (Zhang & Hocking, 2022).**

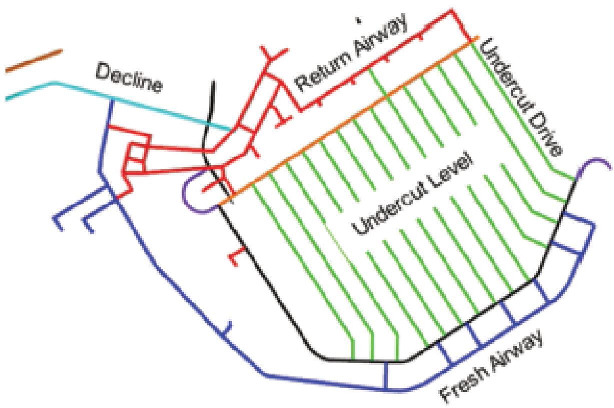

Figure 8 **Carrapateena proposed undercut level with fresh and return airway (Zhang & Hocking, 2022).**

Figures 7 and 8 describe an example of the BC design proposed for Carrapateena (Zhang & Hocking, 2022), where the combination of tunnels from extraction levels was designed to optimize the long-term stress management and efficient for LHDs to bog the draw point and connected to the undercut level to provide ventilation and ensuring the undercut strategy is correctly defined.

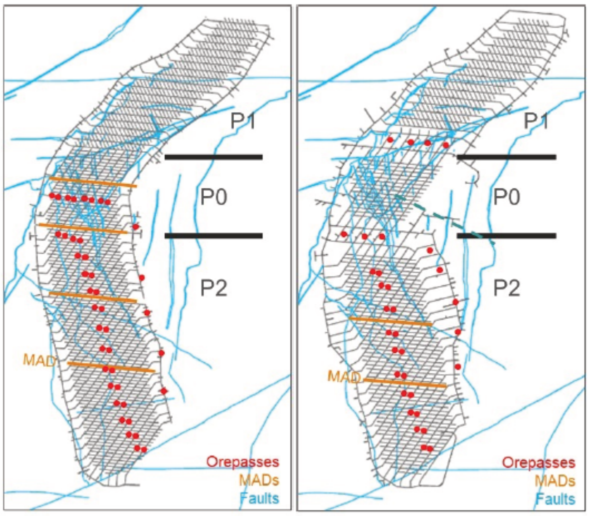

Figure 9 Oyu Tolgoi alternatives mine design.

Another example was presented by Rio Tinto at Oyu Tolgoi (Stegman, Togtokhbayar, Herselman & Altankhuu, 2022), where the structural model's uncertainty requires flexibility in defining the layout of the production level to analyze different options for Panel size, ore passes location, draw point spacing, etc. (see Figure 9).

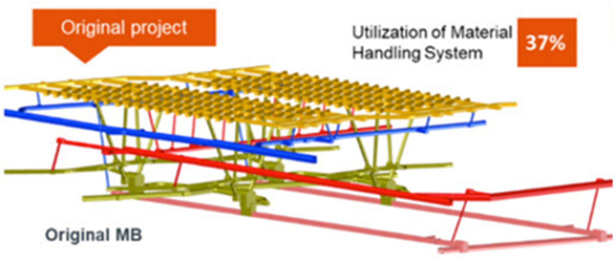

Figure 10 Original Chuquicamata BC design (Araneda, 2020).

Figures 10 and 11 describe the benefit of analyzing multiple options to optimize the design in terms of the number of developments and utilization of infrastructure created, accelerate the start of production, and then improve financial KPIs.

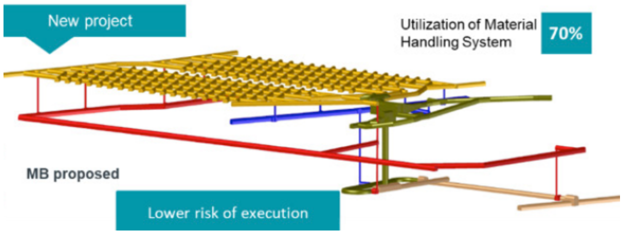

Figure 11 Optimized Chuquicamata BC design (Araneda, 2020).

3.1 Parametric Mine Design examples for Block caving

The spacing between extraction points can be adjusted to explore different options for maximizing the economic value of the mining area, increasing ore extraction, or improving stability. However, making these modifications can take weeks or months because it requires subsequent changes at other levels. Parametric Design offers a quicker solution. Figures 12 and 13 show the initial design, which will be modified to demonstrate how this technique automatically updates the extraction and undercut levels.

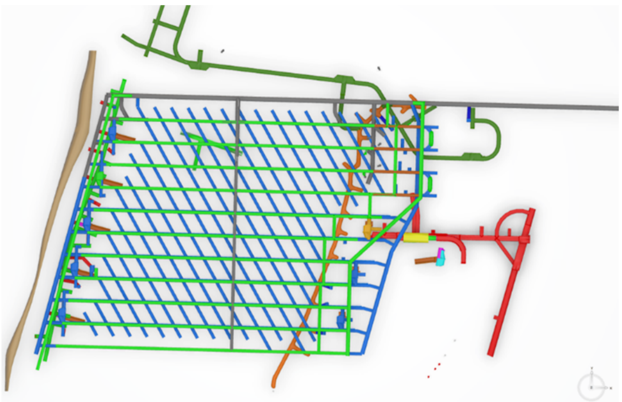

Figure 12 Block Caving mine layout.

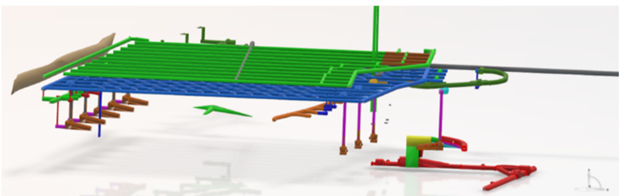

Figure 13 Block Caving mine layout.

According to the design criteria, a set of parameters could be utilized to control this layout. In Figure 14, various items, like tunnel spacing, width, and height are used to manage specific aspects of the design. For example, "minor_pillar" determines the draw bell spacing, while "west_offset" controls the distance of the connection tunnel at the undercut level from the access, and "geology_offset" defines the distance from the fault (brown solid).

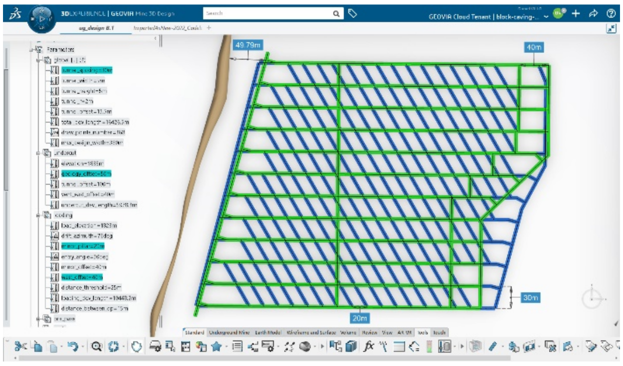

Figure 14 Block Caving design parameters.

3.1.1 Changing draw bell and tunnel spacing for Extraction and Undercut levels

In this example three layout configuration were tested to illustrate the adjustment in the entire design, Table1 describe BC design scenarios modelled.

Table 1 BC design scenarios

	Figure15	Figure16	Figure17
Tunnel spacing	25m	30m	35m
Draw bell spacing	15m	20m	22m

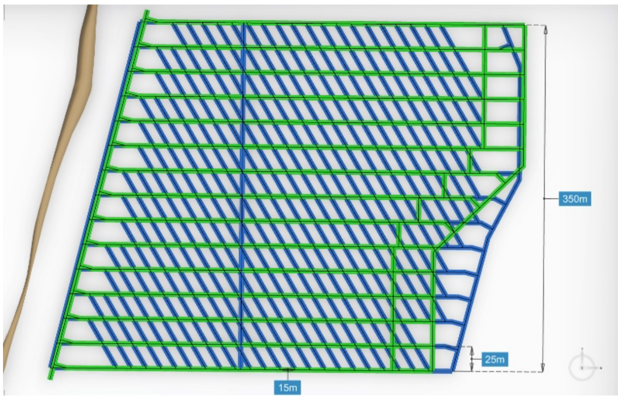

Figure 15 BC design – layout 25x15m.

In these examples, the design criteria are defined for each tunnel at the extraction level, and a corresponding tunnel is created at the undercut level. Therefore, any changes made to the extraction level will also affect the undercut level. Figures 15, 16, and 17 show the resulting new designs. Furthermore, other elements, such as draw points and access tunnels, are automatically adjusted based on the defined design criteria and rules.

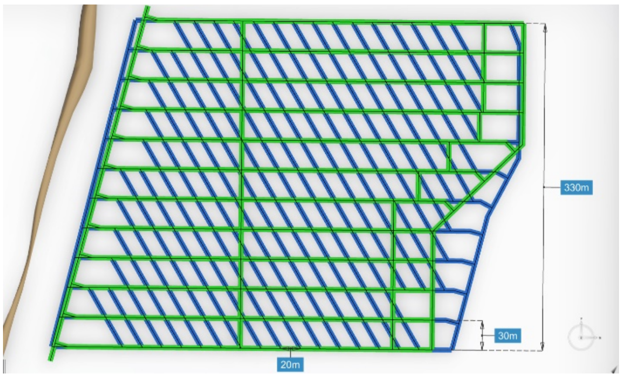

Figure 16 BC design – layout 30x20m.

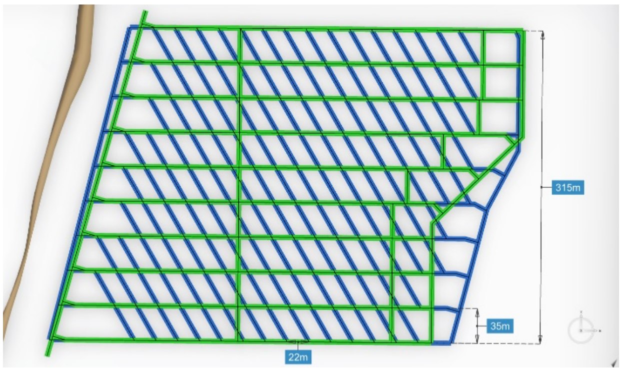

Figure 17 BC design – layout 35x22m.

Table 2 summarizes tunnel and draw bell spacing changes applied.

Table 2 Summary of changes due to tunnel draw bell spacing adjustment

Tunnel spacing	25m	30m	35m
Draw bell spacing	15m	20m	22m
# Tunnels prod. level	15	12	10
# Draw points	632	368	274
Total dev. Length	21,624m	16,426m	13,945m

3.1.2 Changing Draw bell at Extraction level

A second example is presented by adjusting only the draw bell spacing and how this change the extraction level to be updated automatically (see Figure 18 and Figure 19). This modification generates a new distribution of draw points generation on each side of the footprint, allowing repeatability with other designs.

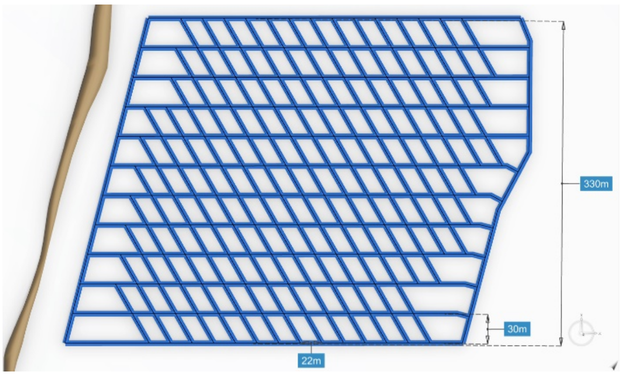

Figure 18 BC design - 22m draw bell spacing.

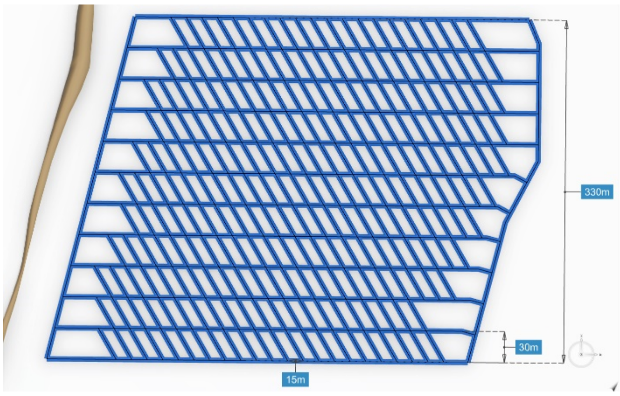

Figure 19 BC design - 15m draw bell spacing.

Table 3, shown below summarizing draw bell spacing changes applied to the production level.

Table 3 Summary of changes due to draw bell spacing adjustment

Tunnel spacing	30m	30m
Draw bell spacing	22m	15m
# Tunnels prod. level	12	12
# Draw points	336	496
Total dev. Length	15,872m	18,644m

3.1.3 Adjustment due to offset from a geological contact

Finally, this example illustrates the capabilities of the parametric model by making automatic changes due to constraints associated with external elements of the design, in this case, due to offset from a geological contact or structure. Figure 20 shows the design controlled by a 50m offset from a fault, which means the access cannot be developed within that range from a 3D solid representation of this structure; therefore, draw points could not be constructed as well.

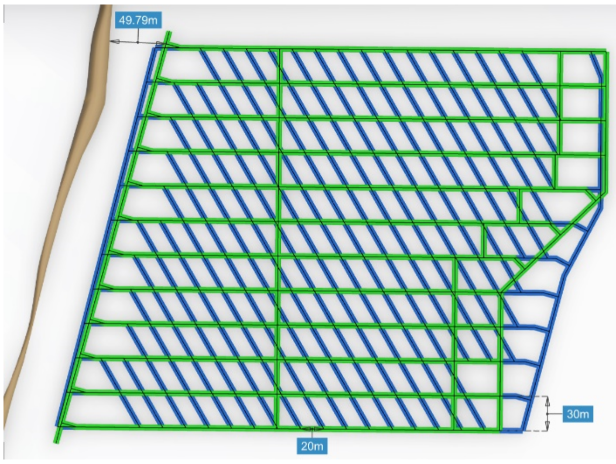

Figure 20 BC design controlled by 50m offset.

Figure 21 shows the adjustment made to the entire design by changing this offset to 25m from the fault. This adjustment allows for increasing the number of draw points from 368 to 396; therefore, this footprint's ore recovery will also increase.

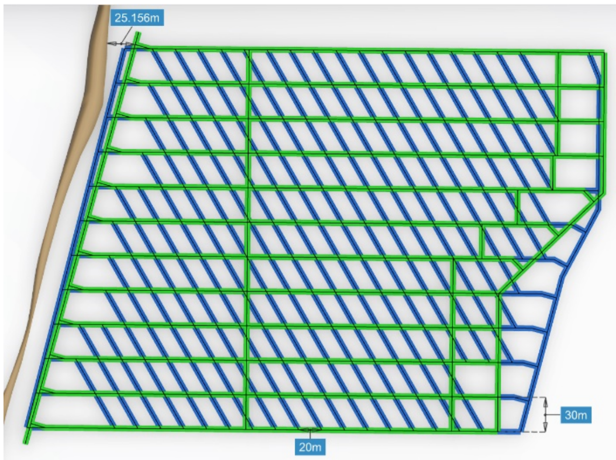

Figure 21 BC design controlled by 25m offset.

Table 4, shown below, summarizes changes applied to the production and undercut levels due to offset from a fault.

Table 4 Summary of changes due to offset from a structure (fault)

Geology offset	50m	25m
Tunnel spacing	30m	30m
Draw bell spacing	20m	20m
# Tunnels prod. level	12	12
# Draw points	368	396
Total dev. Length	16,427m	17,462m

4 PARAMETRIC DESIGN & MINE PLANNING

The parametric design can be integrated with another phase of the analysis using tools like mine planning software PCBC (Diering, 2000) to utilize draw point distribution and evaluate the mine reserve (Villa, Romero & Soto, 2022). PCBC enables the calculation of tonnage, grade, and dilution allocated per draw point to assess the mine reserve based on economic parameters for each design created in the previous step. In Figure 22, you can see how the design is modeled in PCBC, creating draw columns for each draw point, and allocating tonnage, grade, and dilution from the block model to estimate the mineable reserve. This is done by calculating the optimum economic height of the column based on the cost, metal price, and recovery.

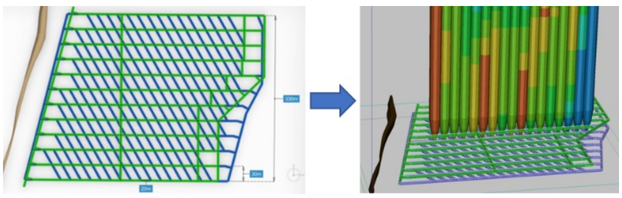

Figure 22 Integration of Parametric Design and mine planning (PCBC).

4.1.1 Mine reserve impact due to design adjustment for draw bell and tunnel spacing

Making adjustments to design parameters such as tunnel and draw bell spacing can impact the distribution of draw points, causing them to be separated. Consequently, the draw columns will also be separated. In Figure 23, the draw column distribution for draw cones in a 30x20m layout looks good, with the interaction between them being particularly above the undercut level. However, in Figure 24 (35x22m layout), where the draw points are more separated, the overlap is smaller. This increases the pillar size and reduces the interaction between draw points, thereby decreasing the ore recovery.

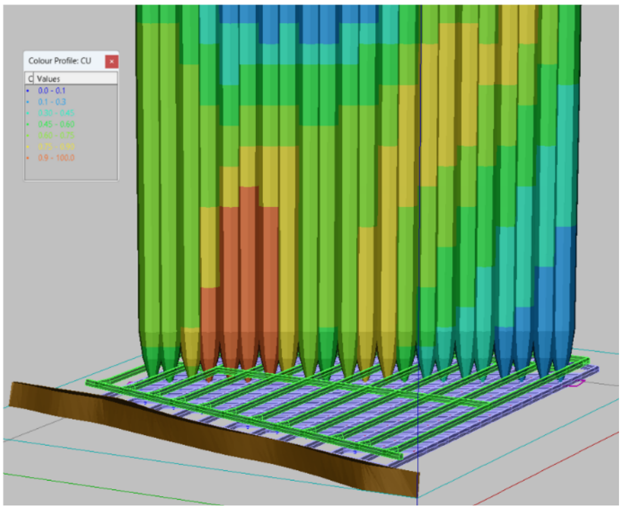

Figure 23 PCBC model for 30x20m layout.

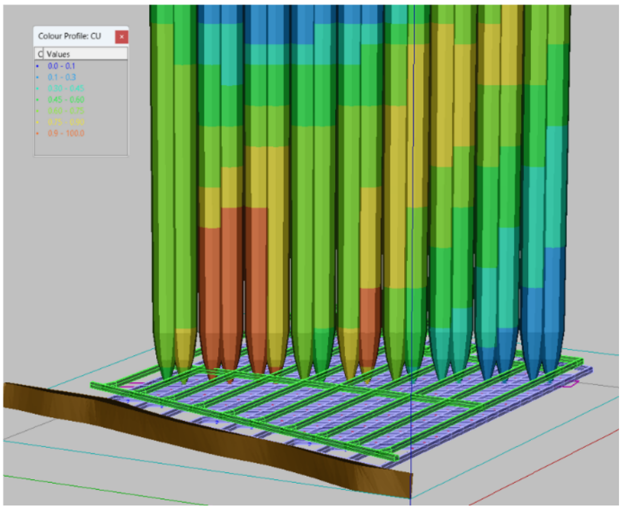

Figure 24 PCBC model for 35x22m layout.

Table 5 displays the impact of the design adjustment on mine reserve. The larger layout shows a 15M reduction in tonnage and a 15% decrease in economic value.

Table 5 Summary of mine reserve due to changes draw bell and tunnel spacing

Tunnel spacing	30m	35m
Draw bell spacing	20m	22m
# Draw points	368	274
Tonnage	108.7Mt	93.3Mt
Cu grade	0.70%	0.69%
Economic value	1.73B$	1.48B$

4.1.2 Mine reserve impact due to offset adjustment from a geology contact

The following example shows the results of the mine reserves for scenarios constrained by a geology offset. Twenty-eight draw points were added to the original footprint by reducing the limit from 50m to 25m. These new draw points are located in high-grade areas, resulting in a 9% increase in the amount of ore extracted and a 17% increase in the economic value of the mining area (see Table 6). Consequently, the additional development cost is justified by the increase in ore reserve and economic value added.

Table 6 Summary of mine reserve due to changes in the offset from a geology constraint (fault)

Geology offset	50m	25m
# Draw points	368	396
Tonnage	108.7Mt	118.8Mt
Cu grade	0.70%	0.73%
Economic value	1.73B$	2.06B$

5 PARAMETRIC DESIGN & MINE PLANNING AUTOMATION

The analysis integrates parametric design and PCBC with other tools like Process Composer (Dassault Systèmes 2020) to automate the process. This integration allows for programming changes in the input design parameters, executing the parametric design, calculating mine reserve in PCBC, and collecting results in a simple manner. The results can then be analyzed using statistical tools in both 2D and 3D. Figure 25 provides an example of the workflow for integrating Parametric Design and PCBC.

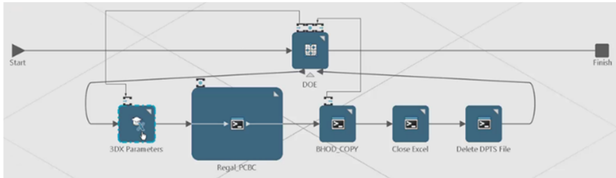

Figure 25 Integration of Parametric Design and PCBC workflow.

The overall steps for the automation process are summarized below:

Parametric Design is automated to create new draw point distribution due to changes in the extraction level and simulating several alternatives (Figure 26)

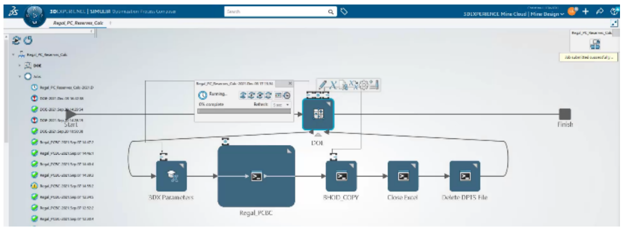

Figure 26 Parametric Design simulating scenarios.

PCBC runs automatically and calculates tonnage, grade and dilution allocated per draw point to assess mine reserve based on economic parameters for each design created in the previous step (Figure 27).

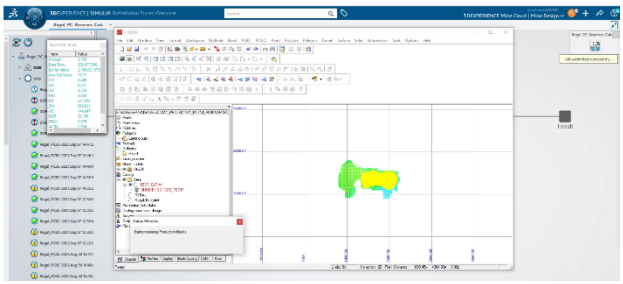

Figure 27 PCBC calculates mine reserve automatically.

Scenarios simulated are summarized where inputs and results could be analyzed and studied to understand the impact of the adjustments done not only in terms of development but also connected with mine reserve (Figure 28).

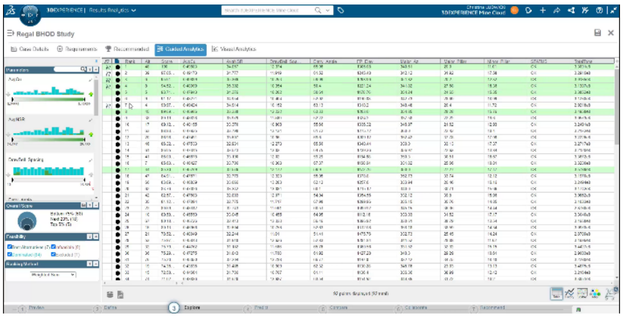

Figure 28 Inputs and results summary table.

All the different design modelled are summarized and presented in a simple way. This summary makes it easier to analyze and understand the results and how they are connected to the different situations. Figure 29 shows a 3D scatter plot that is used to visualize situations with the best economic results (z-axis) based on the combination of reported tonnage (y-axis) and footprint elevation (x-axis)..

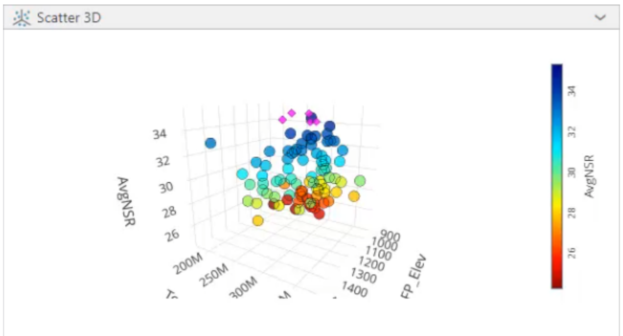

Figure 29 Data analysis using 3D scatter plot.

Figures 30 and 31 show how the extraction level's elevation impacts tonnage and economic value in different design scenarios. These scenarios include variations in tunnel and draw bell spacing, which should all be considered when making the final design selection.

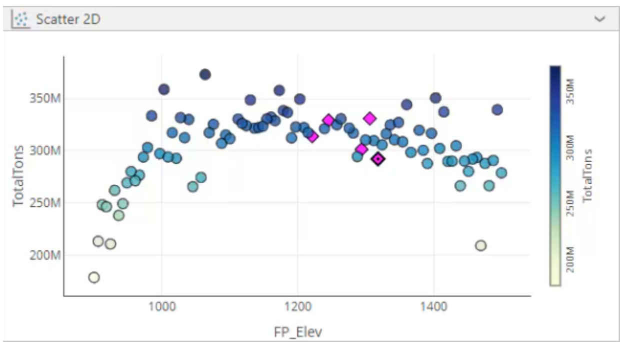

Figure 30 Data analysis - 2D scatter plot (tonnage vs Footprint Elevation).

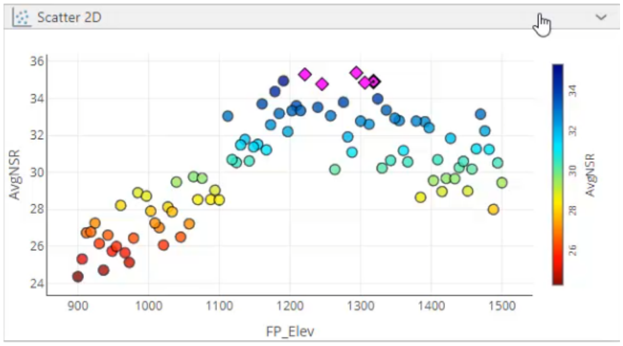

Figure 31 Data analysis - 2D scatter plot (Economic value vs Footprint Elevation).

Finally, the best scenarios could be selected from all runs using filters and based on KPIs defined, where the final preference of scenarios could be easily compared, highlighting differences between them to choose the best options or alternatives for more detailed analysis (Figure 32).

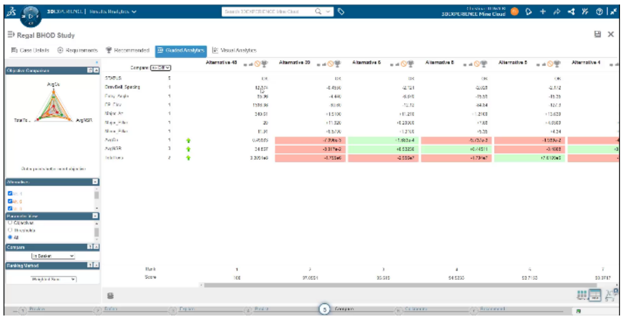

Figure 32 Inputs and results capture in the workflow.

6 CONCLUSIONS

The parametric model is a new solution for designing underground mines. Several examples in this paper demonstrate its effectiveness and lead to the following conclusions:

- Traditional mine design is a manual process, where any change can take weeks or months of design hours, limiting the ability to study various design alternatives.
- The parametric design enables the control of the entire design based on criteria and rules, allowing automatic updates for the whole of the layout when one or multiple parameters are modified.
- It offers options to create various designs that connect different levels (extraction,

undercut, ventilation, haulage, etc.) and visualize the impact of these changes in 3D on the entire layout. This enables engineers to promptly identify errors, weaknesses, or inconsistencies by analyzing the safety of the overall design.

- A trade-off analysis design could be executed quickly to model stability versus ore recovery. By changing parameters such as tunnel and draw bell spacing, a bigger pillar could be generated, but ore recovery would be reduced. Typically, this analysis only uses PCBC and the draw point distribution. However, combining a Parametric design with PCBC can rapidly produce a strong solution by integrating mine layout design with mine reserve analysis.
- Integrating geotechnical and geological constraints inputs ensures improved safety and stability in the design.
- Finally, the process can be fully automated, allowing the simulation of multiple scenarios and measurement of their results in various ways, combining several aspects before making the final decision.

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REFERENCES

Araneda O. (2020). Codelco: Present future and excellence in projects. In Massmin 2020 Conference on Proceedings of the Eighth International Conference & Exhibition on Mass Mining (pp. 1-9). Chile: Universidad de Chile.

Dassault Systèmes (2020). Introduction to Isight, internal learning module.

Diering T. (2000). PC-BC: A Block Cave Design and Draw Control System. In Massmin 2000 Conference on Proceedings of the Third International Conference & Exhibition on Mass Mining (pp. 469-484). Australia: The Australasian Institute of Mining and Metallurgy.

Mining Journal (2020). Freeport said to continue focus on Grasberg, not M&A article: https://www.mining-journal.com/m-a/news/1378907/freeport-continue-focus-grasberg.

Stegman C., Togtokhbayar O., Herselman S. & Altankhuu B. (2022). Oyu Tolgoi: engineering a Mongolian caving dynasty. In Caving 2022 Conference on Proceedings of the Fifth International Conference on Block and Sublevel Caving (pp. 625-634). Australia: Australian Centre for Geomechanics.

Villa D., Romero J. & Soto N. (2022). Multi-lifts selection using scenario simulation and financial metrics. In Caving 2022 Conference on Proceedings of the Fifth International Conference on Block and Sublevel Caving (pp. 51-66). Australia: Australian Centre for Geomechanics.

Zhang Q. & Hocking R. (2022). Carrapateena block cave mine design and planning: feasibility study. In Caving 2022 Conference on Proceedings of the Fifth International Conference on Block and Sublevel Caving (pp. 291-302). Australia: Australian Centre for Geomechanics.