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INNOVATIONS IN MINE PLANNING AND DESIGN UTILIZING COLLABORATIVE IMMERSIVE VIRTUAL REALITY (CIRV)

Peter K. Kaiser, John G. Henning, Luigi Cotesta
MIRARCO.org, Laurentian University, Sudbury, Ontario, Canada

Andrew Dasys
Objectivity.ca, Sudbury, Ontario, Canada

ABSTRACT

Planning and design of deep underground mines involves a process of complex three-dimensional data integration utilizing information from exploration (geology, rock mass characteristics), engineering (mining method, excavation geometry, stress) and operations (time, in the form of sequencing). As new logging and monitoring technologies are being developed, the amount and data complexity becomes overwhelming and decisions are often made based on only a small part of the available data.

Recently, Laurentian University opened a state-of-the-art Virtual Reality Laboratory (VRL), a Mining Exploratorium that is unique in the world of mining and offers an exceptional data interpretation environment for mine planning and design. The Mining Exploratorium combines a large format spherical stereoscopic projection system, equipped with high definition projection providing the highest resolution of active stereo in the world today, with advanced features of earth modeling software. Combined, this creates the first virtual reality facility geared specifically to the interpretation of mine geometry, geology, geochemistry, microseismicity, geomechanics and mining data sets.

This paper demonstrates how value can be added to the mine planning and design process by utilizing this unique tool in the mining decision-making process via better comprehension of spatial relationships of data and by interpreting the data in a collaborative immersive virtual reality environment.

1. VIRTUAL REALITY LABORATORY FOR THE MINERAL INDUSTRY

In September 2001, Laurentian University officially opened a state-of-the-art Virtual Reality Laboratory (VRL) as part of its Centre for Integrated Monitoring Technology (CIMTEC). This facility, designed to meet the needs of the mineral exploration and mining industries, offers a team interpretation environment for earth modeling applications. MIRARCO-Mining Innovation is operating the facility and is undertaking a research and development program to bring the five dimensions of mining: space (*x*, *y*, *z*), time (t) and money ($) together to create a *5D Mining Exploratorium.*

CIMTEC's Virtual Reality Laboratory (VRL), shown in Figure 1, combines a large format spherical stereoscopic projection system with advanced earth modeling software. The system projects three dimensional, dynamic images onto a 9 x 22 foot curved screen, providing up to 20 persons in the theater with the sense of being immersed in their data sets. Mine geometry, geology, geochemistry, geomechanics can all be combined to provide a holistic overview of any property. The facility builds on technologies developed and proven in such fields as oil and gas exploration, equipment design and climatic/environmental modelling. The main benefit for multi-disciplinary teams is the speed with which complex subsurface models can be interpreted, explained and evaluated.

Figure 1. The Virtual Reality facility at Laurentian University

2. BACKGROUND ON VIRTUAL REALITY

Although virtual reality (VR) is thought of as new technology, early systems can be traced back almost 50 years to flight simulators built by the U.S. Air Force during and after World War II. Student pilots could master the intricacies of maneuvering airplanes whilst sitting in a cockpit, which was mounted on a moving platform. Hollywood filmmakers experimented with stereoscopic filming techniques during the early 1950's. These technologies were the earliest attempts at placing individuals in simulated environments and would play a key role in influencing the technology we know today.

> *The terms* virtual worlds, virtual cockpits, *and* virtual workstations *were used to describe specific projects. In 1989, Jaron Lanier, CEO of VPL, coined the term* virtual reality *to bring all of the virtual projects under a single rubric. The term therefore typically refers to three-dimensional realities implemented with stereo viewing goggles and reality gloves.* (Krueger, 1991)

> *Virtual reality (VR) has typically been portrayed as a medium, like telephone or television. This new medium is typically defined in terms of a particular collection of technological hardware, including computers, head-mounted displays, headphones, and motion-sensing gloves* (Steuer, 1992).

Early definitions of VR are hardware centric by nature. However, the definitions fail to provide the reader with the benefits that VR users derive from employing such systems. This has been the underlying problem with VR since it's infancy because developers tried to push the limits of the hardware rather than focus on how it could provide researchers, engineers and scientists new insights into their existing data. VR was a technology looking for a problem.

Virtual Reality is a term that is being used today in a number of different contexts. Web based virtual reality has become very popular using Virtual Reality Modeling Language (VRML) models. This is not to be confused with the type of virtual environment described in this paper, where the power of imaging projection technology is used to create a Collaborative Immersive Virtual Reality (CIVR) working environment to increase group collaboration, understanding and effectiveness.

The availability of inexpensive computers and large-scale projectors allowed the oil and gas industry to pioneer the use of VR in the visualization and interpretation of sub-surface models. These types of facilities have been widely adopted by the oil and gas community, largely because of the time savings that engineering and exploration teams gain from reviewing complex seismic data sets using large scale visualization.

3. AN INTEGRATED APPROACH TO MINE PLANNING AND DESIGN USING COLLABORATIVE IMMERSIVE VIRTUAL REALITY (CIVR)

There are no standardized design procedures that mine engineers can readily use. Part of the reason being the shear amount of complexity and variability any given geological setting may provide. Due to the complex nature of geological settings and a mine environment, the task of mine planning and design is not a simple one.

Luxbacher and Kline (1992) suggest that a mine is made up of numerous inter-dependant and inter-linked subsystems. They define the mine planning process as the stage where the correct selection and interaction of all subsystems is determined. This is typically undertaken at the pre-feasibility, feasibility and yearly planning stages of the mining process. The decisions made in the planning process will create boundary conditions limiting the flexibility of the mine design process.

Mine design, on the other hand, consists of the individual design of each subsystem. Figure 2, suggested by Beniscelli et al. (2000), depicts some of the subsystems and design elements needed to fulfill mine planning and design requirements. What is observed from Figure 2 is that a huge amount of data needs to be integrated, numerous interpretations must be made, vast quantities of knowledge must be transferred/captured and throughout the entire process, multi-disciplinary collaboration must take place in order to achieve a sound design, if not optimum. The goal is a selection of subsystems that will yield maximum profitability and safety.

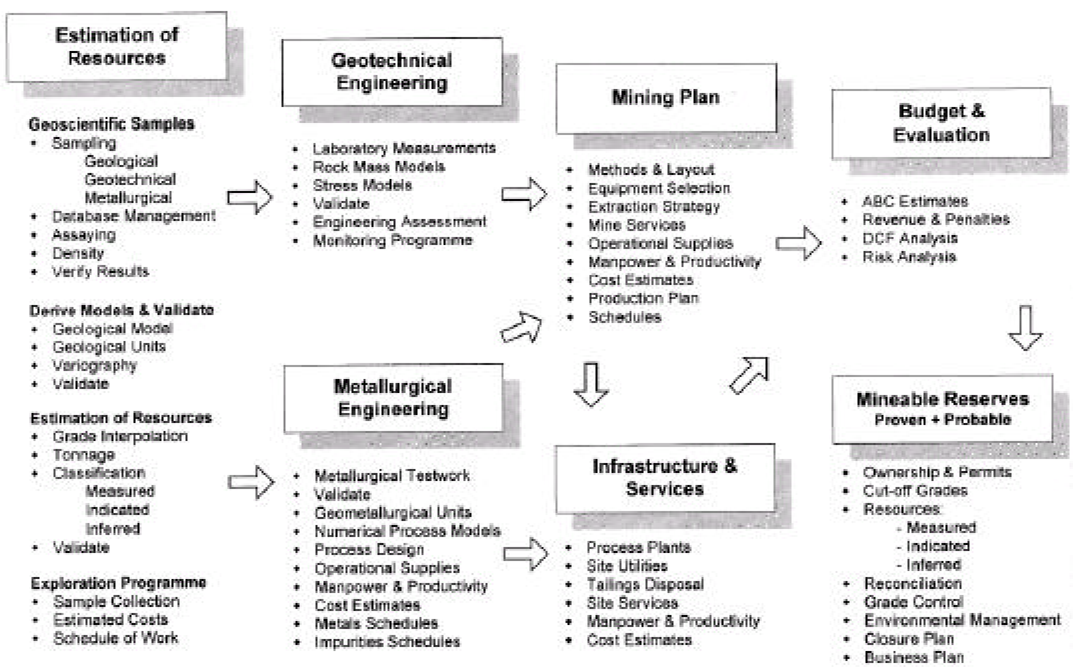

Figure 2. Estimation of resources and conversion to reserves: example of subsystems and design elements required for mine planning and design, (after Beniscelli et al. 2000).

Three-dimensional (3-D) mine planning and design software tools have been around for some time. The benefits derived from such tools have greatly improved the quality of designs as well as the overall economics throughout the mining process. However, unlike most other engineering design processes the tools have not progressed to a point where software predominantly can optimize a design. In part, this is because mining engineering, unlike most other engineering disciplines, has but limited knowledge of the material it must work with, or rather more correctly work within. To make matters more complicated, mining also modifies the principal stresses that surround the mine, thus creating a very dynamic and expanding working/design environment.

Mine design and planning is a difficult, time consuming and expensive exercise. With several individuals bringing unique knowledge or skill sets to the design, communication gaps exist. The constantly changing working environment increases these gaps. As the project advances, large volumes of data are generated. It is usually difficult to keep track of all information, which may result in key elements of the design being missed. For example, it is seldom possible to effectively utilize valuable geological data collected during exploration during the mining method selection and mine feasibility stage.

Today, there is an enormous overflow of data within any given mining company. Mines continually collect and store copious amounts of data, much of which is underutilized. Increased complexity makes it difficult for design teams to use the data to make decisions. New technologies such as simulation are making the problem worse: instead of reducing the data it is actually increasing the amount of data. In an example from the oil industry (Zietlin, 2001), up to 95% of 3-D data collected was not interpreted, since there was simply too much data for the geoscience staff to analyze. Should we believe the mining industry is different? The key to using data in a more efficient manner is to allow design and planning teams a means of identifying areas where data is either "weak" or missing in order to make critical decisions. This can be accomplished within an immersive visualization facility.

Inherent complexities of three-dimensional data can be viewed with a true sense of depth and spatial relationship. The scale of the screen, combined with the depth perception provides an immersion that increases the participants' overall understanding of spatial data relationships and accelerates data comprehension as well as transfer of experience and knowledge. This level of understanding cannot be obtained using traditional computer monitor or projection technology.

The facility uses a number of visualization packages. One of the main packages is the GoCad[1] visualization platform, which allows the "mapping" of all data to a single, world coordinate system. GoCad's object model provides the means of mapping any scalar or vectorial data value to any point in this world coordinate system. This greatly simplifies the integration of data from multiple sources: lithological, geological, hydrological, geometric, seismic, etc. Data fusion occurs when the software's scripting language queries and mathematically processes the data. This fusion provides a "new" view of existing data, identifying hidden relationships or allowing the discovery and explanation of complex data interdependencies.

4. COLLABORATIVE VIRTUAL REALITY FOR MINE PLANNING AND DESIGN: THE MINING EXPLORATORIUM

The real value of the Mining Exploratorium is through the interpretation of 3-D volumes in stereoscopic mode, rather than simply using the facility as a large screen for the presentation of results. The facility has the exceptional advantage of enabling new discoveries of relationships, for decision making and more importantly, for problem solving in a collaborative environment whereby sector experts (such as geologists, engineers, mine planners, operators and financiers), can immerse themselves in complex 3-dimensional data to address strategic questions. Large volumes of data can be evaluated quickly, producing results in a fraction of the time taken using conventional interpretation methods. Teams gain a real advantage by quickly establishing the 'big picture', resulting in a greater understanding of the data.

The Mining Exploratorium is most effectively used with a skilled facilitator that trains and guides the user in the optimal utilization of the VR technology. Ideally, the facilitator is a senior employee of the company using the Mining Exploratorium with extensive practical experience. While the facilitator does not need to have the skills to solve the posed problems, the facilitator must have sufficient technical/scientific know-how to achieve optimal communication between user-team members and the "pilots" who run the 3-D visualization tools, freeing team

[1] Information concerning GoCad can be obtained from Mira Geoscience (www.mirageoscience.com).

members to focus on the technical challenges at hand. The facility is operated by a pilot, who facilitates access to volumes of data hidden in hundreds of data files.

For the last ten years the oil and gas industry has benefited from similar facilities, finding millions of dollars in untapped resources from existing reservoirs by transferring expertise and enhancing collaboration. Key benefits of using Virtual Reality in mine design are:

- Data Fusion
- Knowledge transfer
- Technical conflict resolution, and
- Collaboration.

4.1 Data Fusion

Many individuals at a mine have expertise in unique design components, such as rock mass characteristics, geologic structure, microseismics, stress and past mining performance. A challenge to mine design is the synthesis and timely utilization of all information available from a wide range of sources, and in a wide range of database formats.

The Mining Exploratorium offers the capability to seamlessly integrate a full suite of large and disparate data sets obtained and accumulated during exploration, mine design, excavation and production into a single visual picture. Some examples of data that should be incorporated into an overall mine design picture are compiled in Table 1.

TABLE 1 Examples of Data Sources for integration into Mine Design

Data Source	Examples
Diamond Drill Logs	Geologic delineation, rock mass rating, structure, rock strength, results from geophysical logging.
Geology	Geologic models and interpretation, field mapping records.
Prior mine design experience	Historic stope design, stope production data, excavation geometry, locations of problematic ground, records of backfill quality.
Past mine recovery experience	Stope recovery and dilution records, cavity monitoring results, production rates achieved and mining cost.
Geomechanics	Simulations of stress redistribution, rock mass characteristics, empirical relationships, ground support requirements, microseismic database, rehabilitation locations and cost, rock mechanics instrumentation data.

4.2 Knowledge Transfer

Mine planning involves the transfer of knowledge and technology between disciplines, such as geology, engineering, surveying, accounting, management, contracting. As operations become increasingly complex, effective communication becomes increasingly difficult. Technology and jargon becomes more diverse, computer hardware and software diverges, and staff turnover rates increase the potential for missing key design elements. Methods to improve human capability and reduce error and risk in exploration, mine design, planning and operations will assist in increasing mine safety and productivity.

4.3 Technical Conflict Resolution

Compare and resolve differing interpretations. By seeing the overall impact of various factors in a complex mining environment, mechanisms and patterns associated with mining can be explored. Implications of alternate mining scenarios can be assessed.

4.4 Collaboration

Technical teams working together tend to make better decisions than the best practitioner working alone. Modern 3-D immersive visualization allows a working model to be constructed and evaluated in real time by a technically integrated staff. All team members have a heightened level of understanding, and are able to quickly focus on issues, reach strategic goals and consensus.

The work cycle is substantially reduced, since it is now possible at the onset of a project to review the data, identify prospective regions or trends, assess key technologic challenges, and determine an efficient work direction within a matter of hours.

5. EXAMPLE OF GLOBAL RELATIONSHIPS

The Mining Exploratorium is used to answer key strategic questions. The scope of the question can range from specific mine design concerns, such as sill stability, dilution or support requirements, to global relationships influencing exploitation of an orezone.

Relationships between real data, databases, models and visualizations impacting an orezone can be linked interactively. Benefits to mine design are speed of comprehension, data fusion, and the integration of research findings into a common visualization platform. An example is shown in Figure 3, where elements of regional geology, mine infrastructure, planned and recovered stope geometry, microseismicity, and stress-induced spalling failure are visualized simultaneously. Spalling failure iso-surfaces on stopes were generated by integration of data from two stress relationships[2].

Examining relationships between these variables cannot be properly achieved on a flat surface. With magnification or rotation of the image, peripheral details and depth perception are lost. Only through the use of immersive stereo visualization can such a complex data set be assimilated in a timely manner.

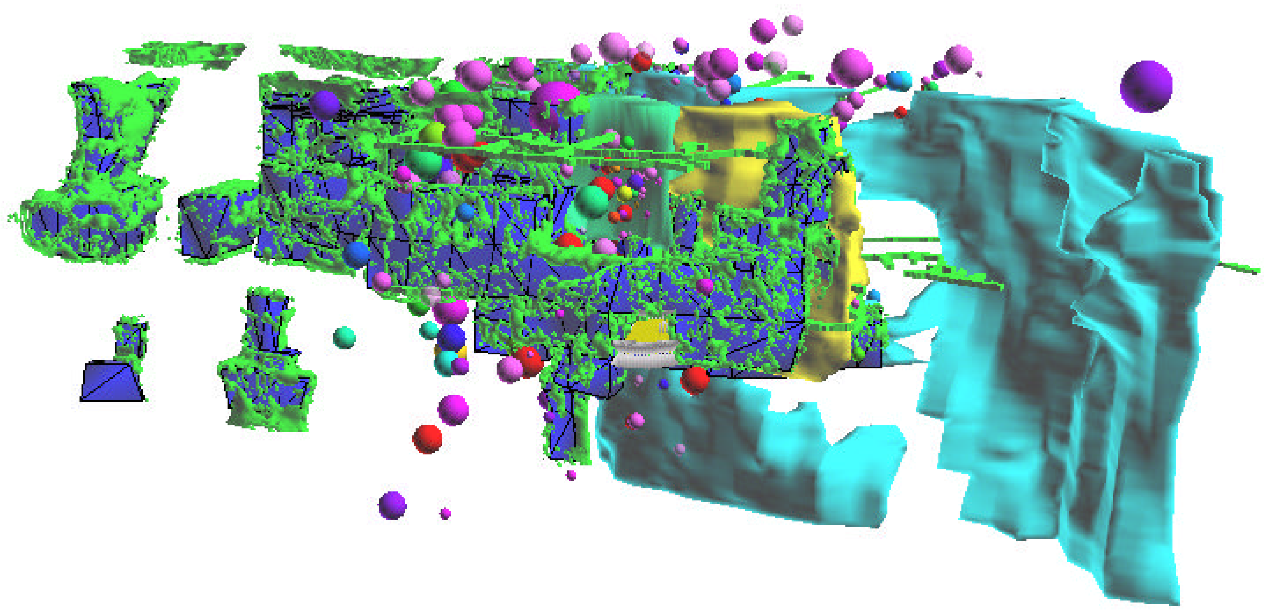

Figure 3. Example of data fusion, combining elements of regional geology, mine infrastructure, planned and recovered stope geometry, microseismicity, and stress-induced spalling failure (mine model courtesy, Noranda Technology Centre, Montreal).

[2] For brittle rock, the bi-linear failure envelope, described in Kaiser et al. 2000, is defined by two stress relationships: the Damage Threshold, defined by Brittle Hoek-Brown parameters: $m = 0$, $s = 0.11$ (Martin et al. 1999), and the Spalling Limit, which represents a region of low confinement zone and exceeding the damage threshold.

6. CONCLUSION

The VR technology of the Mining Exploratorium at Laurentian University is enabling innovations in mine planning and design through a strong capability to visualize overall impact of various factors in a complex mining environment. Key benefits of using Virtual Reality in mine design are data fusion, knowledge transfer, technical conflict resolution, and collaboration.

It is not the quantity or quality of the data, but rather the quality of the decision that is made based on the data, that renders the Mining Exploratorium an invaluable resource for the mining industry. The Mining Exploratorium provides a means of making better decisions based on data that has been collected at great expense. By looking at the forest and not at the trees, the value of existing data can be quantified, and areas of missing data identified in order to make informed decisions.

The immersive visualization represents a huge learning opportunity for anyone using conventional approaches. Why interpret or review data on a conference table when you could get inside the live data and interact with it?

7. ACKNOWLEDGEMENT

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