Information Modelling Guidelines for the Mining Sector

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Abstract –

Mining is rapidly digitalizing and big data surrounds mines in their everyday activities and processes. Building Information Modelling (BIM) has long since taken an indispensable role in the design and management of buildings and infrastructures and is currently widely used as a standard for information management. Based on the results of the workshop series organized by the University of Oulu, a proposal is presented for further development of the concept of Mining Information Modelling (MiningBIM or MIM for short). The purpose of the workshops was to present, prepare and lay the foundation for the development of modelling guidelines for the mining sector. From the participants' point of view BIM is seen as a megatrend that there is no point in trying to stop, and the idea of standardizing BIM in the mining and tunnelling sector is strongly supported. The results of the workshops showed that BIM is already a widely recognized tool and it is worth starting to study and develop further towards MIM and TIM concepts, including also international standardization work.

Keywords –

BIM; MIM; TIM; Modelling Guidelines

1 Introduction

Mining Information Modelling (MIM) enables efficient information management and big data visualization throughout the mining project life cycle. In mining, there has traditionally been an inability to recognize the value of all available information in different parts of the production and processing chain.

1.1 Background

1.1.1 Big data

Digitalization is everywhere in different industries and also in our private lives. Barnewold and Lottermoser [1] describe that "digitalization in the mining industry refers to the use of computerized or digital devices, systems and digitized data that are to reduce costs, improve business productivity, and transform mining practices."

The mining world is rapidly digitalizing and big data, or mass data, surrounds mines everywhere in their everyday activities and processes. " With big data, the key to success is to turn a huge repository of data into a functional intelligence and get value from it. The mining industry can significantly benefit from implementing big data and real-time data analysis" [1].

1.1.2 From data to information models

Data, that is, facts and statistics collected for some reference, must always be presented somehow. Raw data itself is worthless, but it is important and worth refining. "In a mine, the entire tunnel design information", according to Koch et al. [2], "is traditionally available in the form of independent, dispersed, and heterogeneous data files, and since data sources are barely linked in practice, unilateral decisions are made that do not consider all relevant aspects". So when structured or unstructured data exists, it often needs to be shared and combined with other data sources to enable data fusion. "The project data, that is typically shared among the team members of organization, varies also in terms of type, scale, format, and life cycle phase" [2]. Figure 1 shows the authors' view of the trajectory from raw data to advanced target setting.

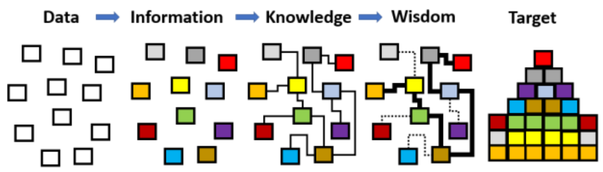

Figure 1. Trajectory from raw data to advanced target setting

The use of data makes it possible to make future actions smarter. The true value of data is determined only when decisions are made based on the information, i.e. when some given data or learned data is put into practice or passed on in some form. All relevant information collected from the mining process lays the foundation for the mine's decision-making process as knowledge, i.e. data, information and skill combined with an understanding of the topic. The wisdom gained after that can be used to achieve the goals set. Analyzing and real-time utilizing the relevant information accumulated with the help of big data is a key part of the mine's information management process. Likewise, "stable, economical, and sustainable design and construction of all underground facilities requires reliable knowledge regarding the expected impacts of the used construction method on the built environment" [2].

Huang et al. [3] state, that "when semiautonomous or autonomous mining platforms, used for data acquisition are combined with machine learning, and especially with deep learning, information of the built environment can be managed to build knowledge forward and create values". According to Willmott [4], "the future for mining in which many assets are operated by machines that run automatically or autonomously means, that the only capability that will matter, is going to be the ability to make decisions based on the information those assets provide. Having the right data at the right time and the tools and capabilities to understand and manage the data is becoming absolutely fundamental to business success". This means that in the future, all relevant industrial information must be structured, modelled, and visualized in information models in order to process and manage it efficiently in the human-machine interaction process. Figure 2 shows the authors' view of the pursuit of desired values based on the benefits of utilizing information modelling and automation.

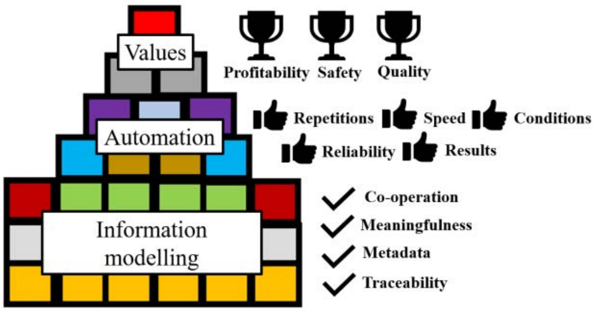

Figure 2. The benefits of information modelling support the benefits of automation to achieve the desired values

According to Slansky [5], "big data can be used especially in information modelling to support advanced analytics applications to discover the flaws and to achieve continuous process improvements and determine best practices across the whole design or build lifecycle".

1.1.3 BIM

The information model is described by Li et al. [6] so that it is a "3D information integration technology based on Computer Aided Design (CAD). It is a digital and visual expression of the physical and functional information produced in the engineering construction and management process. Information modelling includes two main aspects: information integration and 3D geometrical modelling".

There are numerous options for describing BIM. The definition of BIM varies in different contexts and also from different perspectives. Australasian authors of the National Guidelines for Digital Modelling [7] defined BIM in 2009 as "a three-dimensional representation of a facility based on objects including some information about the objects beyond the graphical representation".

In building construction, BIM has long played an indispensable role in the design and management of buildings, where it has been widely used as a standard for information management [8]. In practice, BIM has been widely applied in design and construction phases, while applications in the facility management and operation phases are still at a very early stage [9][10].

According to Hegemann et al. [10] it is important to "include only those data in the BIM model that are required for evaluations to avoid overloading the model and, thus, losing the clarity that makes a BIM model so valuable". A collaborative process of information modelling is defined as OpenBIM that shares process information and supports seamless collaboration for all process participants throughout the process lifecycle, implementing open, neutral data exchange formats [11].

62 research articles related to BIM and 171 case studies have been reviewed, and it has been found that BIM plays a much less role in underground tunnelling than in building construction. Only very few applications focus on maintenance and much less on tunnel maintenance [9]. To achieve the benefits of BIM also in underground tunnelling (Tunnelling Information Modelling, TIM), approaches have been proposed to extend the BIM concept to underground infrastructure projects as well, in order to facilitate design and analysis tasks and thus increase the productivity in design, construction, and operation [12][13]. In the same way, this paper now provides a built infrastructure information modelling (InfraBIM/I-BIM) approach to increase the potential of the mining sector to further develop the concept of Mining Information Modelling (MIM) for mining as well.

1.2 Mining Information Modelling (MIM)

Fraser [14] states, that "issues related to communications in mining like data exchange and interoperability, need to be overcome in future mines and industry-wide standards need to evolve. Then ultimately, transformational productivity gains will be realized by combining an enhanced knowledge of the resource with the improved control of mining and milling systems, and an ability to optimize or tailor all mine activities as a whole-of-business, end-to-end process".

In Australia CSIRO [15] has stated that "a standard for data communication and data base architecture must be agreed among the mining and tunnelling community before information exchange is practical between different data sources of the mine's production processes. When instruments and communications comply with the standard, then the industry will access the benefits of maximum interoperability allowing machines and mining systems to model and react to changing conditions in real time". CSIRO has named this overall concept as The Common Mine Model^{TM}. Also, according to CSIRO [16] the "first of the seven fundamental components for the successful operation of the future mine is a knowledge driven database model that is common and accessible across all activities of the mining operation".

In China, the term Digital Mine is used instead of BIM, and its essence is Mining Information Model to store all mine-related information [17]. MIM in that context is a "digital expression of the mining resources, mining environment and mining engineering objects and a digital re-engineering of the mine life cycle's business processes to realize information interoperability, information sharing and collaboration of various business entities and to solve the problem of information islands in the mining industry and to improve the efficiency and quality of the participants" [17].

According to Wang J. et al. [18], "hardware and software products in the whole life cycle of mines, lack uniform data standards and specifications and therefore each system has its own data format and storage file and the phenomenon of "information islands" is serious. Therefore, a theoretical framework of Mining Technology Collaboration Platform (MTCP) has been proposed. Under the guidance of the BIM idea, the information island problem, as well as information loss, redundancy, duplication, inconsistency, and other issues can be well resolved". Du et al. [19] also suggest that "for creating high yield and high efficiency mining production, mining companies should develop the formerly mentioned Digital Mine concept rapidly".

However, the target functionality of most BIM tools designed for architecture and building modelling is not very well suited for mining projects. Editing custom parameter objects and object families becomes inevitable. "While still pending full standardization, the application of BIM in tunnel projects requires customized solutions for many aspects of design and construction phases. Ground characterization and geospatial location information are vital to the establishment of as-designed underground BIM model. The inclusion of ground conditions and geotechnical data into the BIM model also improve the quality and the usefulness of the mining model, not only during the design phase but also, and in particular, during the construction and the lifecycle management of the infrastructure, as a support to decision making process. Geological and geotechnical issues are thus the most important part of underground infrastructures design" [20].

In the course of this research, it has become clear to the author that there is already a fairly well-established description of TIM in the tunnelling sector. But it has also become clear that for the mining sector the overall picture of MIM, and therefore of the real research gap, is not at all so mature. In mining, certain elements of BIM already exist, for example, 3D models are widely used, but very rarely any information is associated with these model structures.

The route from traditional construction BIM and GeoBIM domains to InfraBIM and TIM development, the BIM path is leaning towards more precise MIM definitions. Based on existing examples and very good experiences of developing the InfraBIM domain in Finland since 2013, the need to start further research on MIM and find out its benefits for the mining sector is highlighted. Figure 3 shows the authors' view of the development path of BIM technology towards MIM and its potential for utilization, especially in machine control (MC).

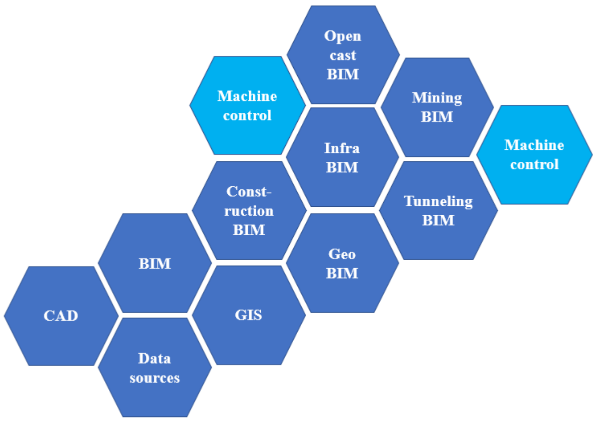

Figure 3. The development path of BIM technology towards MIM and its utilization possibilities in MC

One of the great advantages of MIM conceptualization is an open digital model-based operating environment (ecosystem) that enables the efficient use of semi-automated, automatic and autonomous machines and swarms of machines. In the mining and tunnelling sectors, it would therefore enable knowledge-driven and model-based production.

1.2.1 MIM prerequisites

Currently, there are no specific BIM guidelines or other related specifications available for the mining sector. However, the basic modelling idea of MIM is the same as that of InfraBIM based on the OpenBIM concept. The OpenBIM concept is built on the idea that is three basic prerequisites for a successful BIM process: 1) Modelling guidelines, 2) Information classification, and

3) Data transfer formats, see below Figure 4. These key elements must primarily be sound and consistent for BIM management and practice to work. In Finland, the success of the InfraBIM concept implementation is strongly based on this setup.

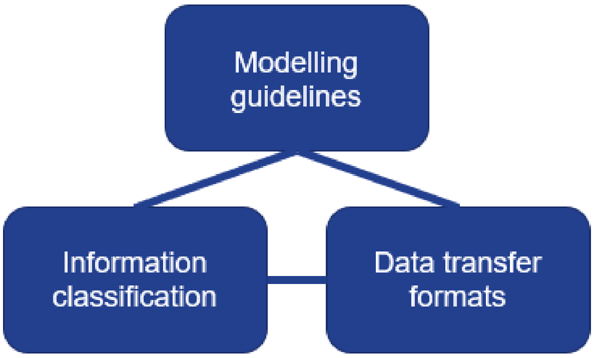

Figure 4. Three key elements in the development and implementation of the BIM process

In this paper, modelling guidelines are discussed mainly because they make up the bulk of the whole. Modelling guidelines tell designers what and how to model. In Finland, these InfraBIM guidelines are called "Common Infra Model Requirements" (YIV-ohjeet in Finnish) [21]. They were prepared in the InfraFINBIM project in 2013 together with companies in the field of infrastructure construction.

Information classification defines the common language on which modelling is based on. "Different stakeholders may use several different data standards and if no common information classification is used, it can result in huge amounts of unusable data and difficulties with exchanging data between different data systems and databases. For tunnelling sector there already exists several different coding systems, one also presented especially for tunnel facility management" [10].

"Common and standard data transfer formats make work machines in the field and computers to talk with central IT systems. Data interoperability is enabled in tunnelling projects with Industry Foundation Classes (IFC) format, which allows data exchange between several BIM software" [2]. Because "IFC provides a well-organized kernel and contains information rich objects used in the construction industry, it is logical to apply to the development of the information modelling in mining, too" [6]. However, there are also many other common data transfer formats available. For example, the IM-format (Infra Model) is used in Finland, where efforts have been made to ensure that all machine control systems support this common and open form of data transfer for earthworks. In USA, the Open Mining Format (OMF) is being developed as an open-source file definition format that supports the transfer of geological and tropological data between software systems.

1.3 Aim of the research

The aim of the research is

- to discuss about the challenges of management of relevant data and information in mines,
- to present the potential of BIM based information modelling concepts and propose the idea of applying InfraBIM and TunnellingBIM concepts into the mining sector, and
- to present the results of the MIM development workshop series on modelling guidelines in Finland and propose the next steps for implementing MIM in the mining sector.

This research paper proposes the introduction of InfraBIM and TunnellingBIM methods in the mining environment, either in underground (UG) or open cast (OC) mines. The idea of creating such a new BIM-based information ecosystem for the entire mining and tunnelling sector is ideally based on the rapid growth of the number of automated and autonomous machines in mines and tunnel construction sites. Therefore, translating physical mining infrastructure into digital infrastructure for machine control purposes is increasingly necessary to enable automation of both single machine and a swarm of machines.

2 Materials and methods

In 2021, an extensive Next Generation Mining (NG Mining) research project funded by Business Finland and Finnish industry was launched in Finland. The project focused on enabling the safe, sustainable and productive use of autonomous and networked non-road mobile machinery in underground mining environments. As part of the research project, which also included the conceptualization of the digital twin, the need to start exploring the OpenBIM concept suitable for the entire mining and tunnelling sector was identified and suggested.

During 2022, the University of Oulu organized a series of workshops series of a total of six special, three-hour-long, online workshops, both for all participants in the NG Mining project and for all key Finnish representatives of the mining and tunnelling sector. The workshops were chosen as a research method in order to create the widest possible discussion of a new topic among specialists from different fields.

2.1 Workshop series

The main goal of the workshop series was to create a consensus-based starting point for the development of new and open Mining & Tunnelling Information Modelling (MIM&TIM) concepts in Finland. In addition, goals were to present BIM and its advancements and opportunities in the mining and tunnelling sectors, to evaluate the experience and best practices already accumulated in InfraBIM and other domains, to stimulate discussion on the needs and objectives of MIM&TIM development, and to explore the possibilities, capabilities and general will to start drafting the development steps of MIM&TIM concepts.

The workshops were carried out, processed, and reported by the University of Oulu, Research Unit of Civil Engineering and Civil Engineering, Digital Construction and Mining Research Area. The workshop series covered six main topics, such as 1) Modelling Guidelines, 2) Information Classification, 3) Data Transfer Formats, 4) The use of building information models in work machine automation, 5) The real-time cloud services of the MIM&TIM process and 6) Organizing models of MIM&TIM future development.

A total of 107 people participated in at least one of the six workshops out of a total of 235 invited people. A total of 54 companies or organizations participated out of a total of 84 invited companies. Throughout the workshop series, online and email surveys were utilized as the most important research tools. A total of 52 BIM-related orientation presentations and numerous group assignments were held in the workshops. Each workshop was recorded and reported in writing with all the results. For the research results, as much as possible of the opinions and experiences of the participants were collected from the workshops, which were then analyzed and summarized by the authors.

3 Results

In the first workshop, the main theme was modelling guidelines and the main topic was the definition of the need for further research and development of the MIM and TIM concepts in Finland.

The main research method was surveys that were conducted before, during and after the actual workshop. The preliminary survey was carried out several days before the workshop using an on-line Webropol software tool, which included five (5) questions related to the main topics of the workshop.

In the actual workshop, the workshop participants gave six (6) well-prepared orientation presentations, which presented all workshop participants with ideas for general BIM and InfraBIM modelling guidelines. After these presentations, a groupwork section was organized with 22 questions using an online Mentimeter software. A total of 53 people from 30 different companies or organizations participated in the workshop. After the workshop, the feedback survey was carried out a few days later using an online Webropol software tool, which included two (2) questions related to the main topics of the workshop.

A total of 29 questions were asked about the main topics and a total of 569 responses were given to these questions. The results obtained from the participants' contribution to these questions were carefully analyzed and compiled in a separate workshop report. The results are summarized by the author in the following sections 3.1-3.3.

3.1 BIM concept in mining

The workshop participants were asked how well the BIM concept would be suitable for mining. The following types of responses were derived and compiled from the participants' responses.

"In Finland, the mining and tunnelling sectors lack a uniform BIM modelling approach. Only minor examples of the implementation of BIM in tunnelling can be found. In the global scale, the tunnelling sector has a maturing BIM approach, but a similar one has not yet been found in the mining sector."

Here are some of the participants' comments on the further development of the MIM concept in the mining sector.

- "BIM is a megatrend – a trend that is pointless to try to stop."
- "Digital tools and systems developed for BIM enable the further development of many other areas."
- "Now is just the right time to move forward with MIM in the mining and tunnelling sectors."
- "There is strong support for the idea of standardizing BIM in the mining and tunnelling sectors."

3.2 Current MIM status

The workshop participants were asked what kind of capabilities are in the MIM implementation. The following types of responses were derived and compiled from the participants' responses.

"The level of BIM expertise may not yet be very extensive in the mining and tunnelling sector in Finland. The mining and tunnelling sector definitely has an interest in starting preparations and research activities in this area. The possibilities and capabilities of BIM have already been clearly identified."

"The use of BIM in other domains has mainly focused only on the first stages of the entire process chain 1) Initial data, 2) Design and planning and 3) Construction. The implementation has not yet had time to extend extensively to the latter part of the process chain, like 4) Maintenance, 5) Production, 6) Termination of operations and 7) Aftercare. The Initial data and Design and planning process stages are strengths in the current Finnish InfraBIM modelling guidelines. The identified specificities of the mining and tunnelling sectors indicate that there are significant needs for change and development towards the end of the process compared to the current guidelines."

"There are already some preliminary and very limited guidelines for the mining and tunnelling sectors, but they are not widespread. There are no actual uniform or common model naming conventions. There are some specifications for geological rock type and characteristics, data produced and processed in the mine's production process and machine utilization, and rock support data. The mining and tunnelling sectors are characterized by longer time horizons and lower, not millimeter scales, accuracy requirements compared to other BIM domains."

"From a software perspective, national capabilities for BIM-based information management work have already been developed to reasonable level in other BIM domains. The number of suitable software applications remains very limited in the tunnelling sector, and in particular in the mining sector."

3.3 Expectations for the MIM

The workshop participants were asked what their expectations are for MIM development. The following types of responses were derived and compiled from the participants' responses.

"The potential of different BIM solutions is perceived as significant. BIM is seen to be needed in many different mining and tunnelling solutions, which enables savings and brings added value to all parties. MIM is seen as an opportunity for high-quality mining, where geological data can be utilized by mining machines in different work phases smoothly together with the material flow, ensuring all interfaces and specifications along the way to the concentrator. It is seen to as useful, especially when looking for a new direction and taking advantage of new opportunities."

"Expectations for MIM development are emphasized by the importance and relevance of cooperation in order to achieve a better outcome through common specifications and established standards. The general need for additional knowledge and learning related to MIM is great. The potential of various BIM solutions in the mining and tunnelling sector is considered to be very high."

"Current modelling guidelines for the building construction and InfraBIM sector can also be applied to the mining and tunnelling sectors. However, due to the peculiarities of mining and tunnelling, the need for changes is estimated to be quite large. Creating new modelling guidelines, and at the same time coordinating old practices in the existing operations will be a challenge. The mining and tunnelling sectors are also likely to need two modelling guidelines, one for each sector separately. However, it may be worth evaluating this in more detail during the actual phase of creating the guidelines and also possibly making use of modularity, for example. In the mining sector itself, two separate guidelines may also be required, considering UG and OC mining. The mining and tunnelling sectors should develop modelling guidelines that are as consistent as possible. Expertise may already exist in other BIM domains and especially in the construction and built infrastructure sectors, and this know-how must be utilized."

4 Next steps

Suggestions of the author of this paper for the next steps MIM development are presented in the following sections 4.1-4.2.

4.1 MIM development

The InfraBIM domain has already reached a high level of BIM maturity in Finland. However, the information classification in the mining sector is quite specific, and therefore the current terminology in the InfraBIM sector should be revised very closely if necessary. The current GeoBIM references would also be useful in defining, for example, solid modelling of ores and other formation rocks, as they are not included in the InfraBIM guidelines.

Further development of MIM's modelling guidelines may be based on the existing InfraBIM guidelines. Where necessary, they should only be adapted to the specific needs of the mining and tunnelling sectors. It is also clear that GeoBIM guidelines must be included in the overall picture of this future BIM domain.

The actual preparation of MIM guidelines should take place in a separate development project. One good possibility would be a co-innovation project involving key experts and actors from different fields. Similarly, development trends in international BIM domains must be taken into account as part of the creation of new guidelines and classifications.

It would also be important to start general international standardization work and/or creation of a White Paper on MIM development. Significant advances in information modelling in mining are most likely to be developed and implemented through a collaborative, multi-party approach and coordinated by an industry-centric steering group. Industrial cooperation is very critical because the technical challenges are extensive and outside any single entity to be solved.

4.2 MIM guidelines

In Finland, the buildingSmart Finland organization is the controlling unit of all specifications related to BIM. The InfraBIM sector has had very good modelling guidelines since 2013.

The author of this paper made a rapid study and a preliminary proposal to assess the need to make possible changes to the current outline of these guidelines if they were applied and implemented in the mining and tunnelling sectors. The proposal was presented and discussed among the workshop participants. It was found that, in fact, little change is needed to the current outline in order to be better suited and to fill in the gaps in the needs of the mining sector. A preliminary proposal for modelling guidelines for the mining sector is presented in Figure 5.

Original table of contents of the built infrastructure modelling guidelines	Proposed table of contents adapted for the mining sector
General inframodel requirements	General mining model requirements
1. General matters	1. General matters
2. Initial data	2. Initial data
3. Design and planning	3. Design and planning
4. Construction	4. General preparatory tunnelling
	5. Excavation and production
	6. Mine closure and afterwork

Figure 5. The main content of the MIM modelling guidelines

The first three headings, which include 1) General matters, 2) Initial data and 3) Design and planning, are also very suitable for the mining sector. The fourth heading in the InfraBIM guideline, Construction, should be looked at in more detail. In the mining sector, it should be opened up more widely 4) General preparatory tunnelling, which would also cover all other tunnelling work in the mine. Also, for the production phase of the actual mine, 5) Excavation and production section, would include all issues related to mining. Finally, 6) Mine closure and afterwork section, would describe all the necessary details of the post-production period. Similar comparisons and suggestions were also made to all subtitles of the InfraBIM guidelines to make them more suitable for the mining sector. However, the results of the these are not presented in this paper but are available from the author.

5 Conclusion

Mines and tunnelling work sites need to work with enormous amounts of data, coming from many different sources like humans, machines, and surrounding environment. Data can be located in many different places at the same time. In the mining sector, 3D-modelling, data management and mine automation are still mainly handled separately. Both the mining and tunnelling sectors lack a unified information modelling methodology for converting physical mining infrastructure into digital infrastructure for machine control.

Various BIM domains have developed very rapidly in recent years and clear benefits have been reported from many industries. InfraBIM, GeoBIM and TIM domains have been continuously developed internationally. The mining sector does not yet have a common OpenBIM derived approach.

Numerous questions were asked in the workshops held in Finland, and the author has analyzed and summarized the results obtained from the contribution of the participants. Based on the results, it was concluded that now is the right time to move forward with MIM in the mining and tunnelling sector. The potential of various BIM solutions was considered significant. BIM is seen to be needed in many different mining and tunnelling solutions, which enables savings and brings added value to all parties. However, specific features have been identified in the mining and tunnelling sectors which indicate that the current guidelines need to be further developed significantly.

A preliminary proposal for the main outline of the MIM guidelines was presented and discussed. Further development of MIM's modelling guidelines could well be based on the existing InfraBIM guidelines. There is strong support for the idea of standardizing BIM in the mining and tunnelling sectors. The need to start researching and further developing the MIM concept in future development projects was identified. It would also be important to start general international standardization work on MIM.

CRediT authorship contribution statement

Jyrki Salmi: Conceptualization, Methodology, Writing, Review & Editing. **Rauno Heikkilä**: Conceptualization, Methodology, Writing, Review & Editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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