14
15-17 NOVEMBER, 2023
AUSTRIA TREND HOTEL
LJUBLJANA, SLOVENIA
International Tunnelling and Underground Structures Conference
Mednarodna konferenca o predorih in podzemnih objektih
ITA SLOVENIJA

DATA-VALIDATED BIM MODEL FOR MONITORING THE EXCAVATION AND PRIMARY SUPPORT OF THE EASTERN TUBE OF KARAVANKE TUNNEL

Dr. Gregor Vilhar, univ. dip. inž. grad | Mitja Pečovnik, mag. inž. geotehnol. | Elvir Muhić, mag. inž. geotehnol., dipl. inž. grad. | Dr. Vojkan Jovičić, univ. dipl. inž. grad.

IRGO

ABSTRACT

In the project of constructing the eastern tube of the Karavanke Tunnel, we are monitoring the progress of excavation and primary tunnel support through the parallel development of a BIM model. This is a pilot project of BIM monitoring for a large infrastructure project in Slovenia. The BIM model of excavation and primary support consists of a geometric and a data part. The role of the geometric part is primarily in spatial positioning and simulating each step of excavation/support, while the data part of the model provides detailed and accurate information that enables processing in terms of quantities, costs, and time progress. A key component of the data model is a properly defined attribute system, which allows for easy and systematic access to all data in the BIM model. In addition to type and quantity values, the data part also includes a time component of construction progress. By referencing the Bill of Quantities, we also have cost information available at any given stage of construction. The BIM model represents a database related to the elements of the 3D space. Due to the enormous amount of data, it was necessary to automate the model creation using using computer algorithms as well as develop methods for managing and ensuring accuracy. For this purpose, we developed a data validation system by establishing a set of validation tests that the computer performs on the entire BIM model. If the expected value of a particular test does not match the calculated value, we are alerted, and the error is rectified. By fulfilling the validation tests, we can ensure the accuracy of the constructed model. Validation tests, among other things, ensure the consistency of the BIM model with the Bill of Quantities and the Construction Book. A properly data-equipped, structured, and validated BIM model serves as a rich database on which we can perform further analysis of construction progress and forecasts with a high level of accuracy.

1. INTRODUCTION

BIM modelling of as-built tunnel excavation and primary support has to frequently adapt to adequately cover the unforeseen design solutions.

The automation of data preparation, algorithms, calculations, preliminary checks and generation of such BIM models have already been presented.

In this paper we present the recent developments at IRGO for BIM data quality assurance and data analyses as applied on as-built BIM model of Karavanke tunnel excavation and primary support.

2. THE MAKING OF THE AS-BUILT BIM MODEL OF TUNNEL EXCAVATION AND PRIMARY SUPPORT

The as-built BIM model of tunnel excavation and primary support has been updated every month according to the collected up till now daily progress data

As the project is progressing the amount of data is constantly increasing, becoming less and less possible to be efficiently processed manually and at the same time to assure the quality of model.

The processing of data and geometry has been automated to a great extent by utilising the in-house computer program MatM:

- The daily progress excel file is imported. In MatM the support elements for the chosen support type are defined and the support numbers and tunnelling classes are simultaneously evaluated.
- All the defined tunnelling classes are stored in the database.
- The attribute specification according to BIM Execution Plan (BEP) is also defined in MatM.
- MatM processes all of the excavation /support steps and outputs the data structures in the form suitable for the generation of 3D geometry elements by using the AutoCAD Civil Plug-in called MatM Assembler.
- Numerous algorithms are employed in the processing of data to get the final attribute values for the BIM model [3].

3.1 AUTOMATIC MANAGEMENT OF DATA IN BIM MODEL WITH MATM

By taking the approach of managing the data with our own developed software solutions, we are able to be very flexible in handling the novel specifics of each project and have full control of data organisation including the access.

One of the primary goals of the construction of BIM models is that the models are equipped with the correct values of attributes subsequently enabling the precise evaluations in terms of quantities, costs and time.

As the construction of tunnel progressed, the amount of data started to grow enormously. As a consequence the new module within MatM has been developed to conduct automated tests to ensure the correctness of quantities.

3.2 BIM DATA VALIDATION THROUGH AUTOMATED TESTS

The selected methodology of checking the attribute values resembles the common unit testing in software engineering.

The core concept involves prescribing as many as possible attribute value tests to be evaluated on the produced BIM model and at the same time covering most of the construction book entries.

If the tests have passed, which means that the evaluated values of tests agree with the expected values of tests, then we can ensure the correctness of attribute values in the BIM model.

3.4 THE COMPLETE FORM OF BIM VALUE VALIDATION TESTS

Every BIM value validation test comprises the following components:

- an optional reference to the pay item in bill of quantities
- name and description of test
- element query
- evaluation formula and
- expected value.

For each test it can be defined if it refers to an existent pay item from bill of quantities or not.

In summary, there are 3 options for defining the element queries:

- complete element query from the reference pay item
- element query from the reference pay item with additional expressions for the test
- element query exclusively defined for the test

The same principle of 3 options can be applied in defining the evaluation formulae.

The partial quantities from the construction book can easily be tested, while simultaneously utilising the pay items from the updated project's bill of quantities.

3.3 FORMAT AND SYNTAX OF ELEMENT QUERIES AND EVALUATION FORMULAE

Simple and transparent access of data: One significant advantage of working with BIM data to evaluate quantities and textual values in contrast to using Excel spreadsheets or other conventional databases.

The element queries and evaluation formulae are employed sequentially to access the requested data and apply the desired evaluation on it.

The proper definition of attribute system is a prerequisite for enabling straightforward querying of geometric elements and their internal attributes.

The supported element query and evaluation formula syntax from Bexel Manager. Table 1 provides a list of supported logical operators for expressing relationships between subexpressions in an element query.

Table 2 presents the supported relational operators that can be employed within subexpressions of an element query to express relationships between attribute names and attribute values of numerical and textual type.

An example of complete element query and evaluation formula for calculating the area of shotcrete of thickness of 20 cm at top heading of the tube is as follows:

- element query: ['ConaTip'] = 'VZC' and ['Sistem'] = 'PRP' and ['ProfilPozicija'] = 'Kalota' and ['ElementTip'] = 'PodpiranjePredora' and ['BBObodTip'] = 'BB_C25/30_XC2_20cm'
- Evaluation formula: [BBObodPovrsina_m2]

Operator	Description	Example
and	Conjunction: expA and expB. If operands expA and expB are both true then the expression is true, otherwise it is false	(['ProfilPozicija'] = 'Kalota') and (['PredorskaStacionazaZacetek_m'] >= 2459.00)
or	Disjunction: expA or expB. If any of operands expA and expB is true then the expression is true, otherwise it is falsew	(['ProfilPozicija'] = 'Kalota') or (['ProfilPozicija'] = 'ZacasniTalniObok')
!	Negation: ! expA. If operand expA is true then the expression is false, otherwise it is true.	! (['ProfilPozicija'] = 'Kalota')
~	Existence of attribute: ~['attributeName'] The expression is true if the geometric element contains the given attribute name.	~['MABBCeloPovrsina_C25/30_5cm']

Table 1: Logical operators supported by the developed MatM module to express relationships between subexpressions in an element query.

Operator	Description	Example
=	Equality	['PodporniTip'] = 'K-8/26,94'; ['Debelina_m'] = 0.2
!=	Nonequality	['ProfilPozicija'] != 'Kalota'
>, >=, <, <=	Inequality	['PredorskaStacionazaZacetek_m'] > 1500.0; ['Datum'] >= '2022-02-05'
in	Attribute can take any of the given values.	in (['PodporniTip'], 'K-6/6,38', 'K-6/4,21'); in (['Debelina_m'], 0.2, 0.3)
%	The value contains, begins with or ends with the given string next to %.	['ProfilPozicija'] = '%Nisa%'; ['AMObodTip'] = 'AM_B500B_Q283%'; ['DeformacijskiElementTip'] != '%Plosca_27cm'

Table 2: Logical operators supported by the developed MatM module to express relationships between subexpressions in an element query.

4.1 EXAMPLE OF BIM VALUE VALIDATION TESTS

In Table 3 a small set of BIM value validation tests is given related to the construction book of May 2023. The tests involve the excavation and shotcrete quantities.

As it can be observed in Table 3, there is a strong agreement between the expected and calculated quantities.

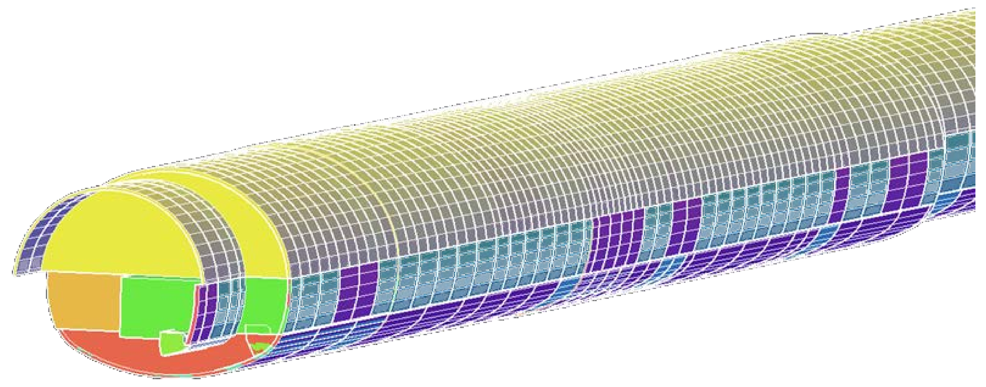

Figure 5: Karavanke tunnel as-built BIM model of excavation and primary support

Pay item outline level	Pay item ID	Pay item description	Test description	Test condition	Calculated value	Expected value	Difference (%)
2.3.1.2.0041	1 N 8 1 141	Izkop kalote predora v hribini s podpornim številom K-7/16.42 (2P)	GK maj 2023 obr.list 200 (2+525,70 - 2+549,70=24m)	and (['PredorskaStacionazaZacetek_m'] >= 2525.70 and ['PredorskaStacionazaKonec_m'] <= 2549.70)	1774,08	1774,08	0,00
2.3.1.2.0051	1 N 8 8 101	Sistemsko pogojeni več izkop žagastega profila pod sulicami (2P)	GK maj 2023 obr.list 210 (2+525,70 - 2+549,70=24m)	and (['PredorskaStacionazaZacetek_m'] >= 2525.70 and ['PredorskaStacionazaKonec_m'] <= 2549.70)	29,79	29,79	0,01
2.3.1.3.0037	1 N 8 2 141	Izkop stopnice predora v hribini s podpornim številom S-6/9.73 (2P)	GK maj 2023 obr.list 248 (2+490,70 - 2+511,70=21m)	and (['PredorskaStacionazaZacetek_m'] >= 2490.70 and ['PredorskaStacionazaKonec_m'] <= 2511.70)	1052,67	1052,67	0,00
2.3.1.4.0003	1 N 8 3 103	Izkop talnega oboka predora v hribini s podpornim številom TO-6/4 (2P)	GK maj 2023 obr.list 259 (2+487,00 - 2+511,70=24,7m)	and (['PredorskaStacionazaZacetek_m'] >= 2487.00 and ['PredorskaStacionazaKonec_m'] <= 2511.70)	657,24	657,24	0,00
2.3.1.5.0016	1 N 8 4 116	Izkop kalote za odstavno nišo v hribini s podpornim številom K-6/14.96 (ON)	GK maj 2023 obr.list 276 (2+549,70 - 2+551,00=1,3m)	and (['PredorskaStacionazaZacetek_m'] >= 2549.70 and ['PredorskaStacionazaKonec_m'] <= 2551.00)	102,66	102,66	0,00
2.3.1.5.0018	1 N 8 4 118	Izkop kalote za odstavno nišo v hribini s podpornim številom K-7/16.48 (ON)	GK maj 2023 obr.list 278 (2+551,00 - 2+554,00=3m)	and (['PredorskaStacionazaZacetek_m'] >= 2551.00 and ['PredorskaStacionazaKonec_m'] <= 2554.00)	252,05	252,05	0,00
2.3.1.5.0021	1 N 8 8 101	Sistemsko pogojeni več izkop žagastega profila pod sulicami (ON)	GK maj 2023 obr.list 281 (2+549,70 - 2+551,00=1,3m)	and (['PredorskaStacionazaZacetek_m'] >= 2549.70 and ['PredorskaStacionazaKonec_m'] <= 2551.00)	2,78	2,78	0,08
2.3.1.8.0023	1 N 8 7 123	Izkop kalote s stopnico prečnika v hribini s podpornim številom K+S-6/9.02 (PRC)	GK maj 2023 obr.list 328 (0+018,20 - 0+024,70=6,5m)	and (['PredorskaStacionazaZacetek_m'] >= 18.20 and ['PredorskaStacionazaKonec_m'] <= 24.70)	376,02	376,02	0,00
2.3.2.2.1.0006	1 N 9 1 108	Brizgani beton C25/30 XC2, ds= 35 cm (TH; 2P+ON)	GK maj 2023 obr.list 396 (2+525,70 - 2+549,70=24m)	and (['PredorskaStacionazaZacetek_m'] >= 2525.70 and ['PredorskaStacionazaKonec_m'] <= 2549.70)	514,27	514,27	0,00
2.3.2.2.4.0002	1 N 9 1 127	Brizgani beton C25/30, XC2 za podpiranje čela, ds=5cm (TH; 2P+ON)	GK maj 2023 obr.list 412 (2+525,70 - 2+554,00)	and (['PredorskaStacionazaZacetek_m'] >= 2525.70 and ['PredorskaStacionazaKonec_m'] <= 2554.00)	1015,60	1036,88	2,05
2.3.2.2.4.0003	1 N 9 1 128	Brizgani beton C25/30, XC2 za podpiranje čela, ds=10cm (TH; 2P+ON)	GK maj 2023 obr.list 413 (2+525,70 - 2+554,00)	and (['PredorskaStacionazaZacetek_m'] >= 2525.70 and ['PredorskaStacionazaKonec_m'] <= 2554.00)	1089,52	1089,52	0,00
2.3.2.2.5.0002	1 N 9 1 127	Brizgani beton C25/30, XC2 za podpiranje čela, ds=5cm (B; 2P+ON)	GK maj 2023 obr.list 415 (2+490,70 (desno) - 2+548,70)	and (['PredorskaStacionazaZacetek_m'] >= 2490.70 and ['PredorskaStacionazaKonec_m'] <= 2548.70)	1783,00	1833,13	2,73
2.3.2.2.7.0001	1 N 9 1 111	Dodatni brizgani beton C25/30, XC2 za zapolnitev žagastega profila pod sulicami	GK maj 2023 obr.list 418 (2+525,70 - 2+549,70=24m)	and (['PredorskaStacionazaZacetek_m'] >= 2525.70 and ['PredorskaStacionazaKonec_m'] <= 2549.70)	30,68	30,68	0,01

Table 3: A set of BIM value validation tests. The reference pay item from the bill of quantities for each test is identified in columns A-C. In column D a brief description of the extent of test is given while in column E the element query of the test is given. The calculated quantity from the BIM model is given in column F, while in column G the expected quantity from the construction book is given. In column H the difference between the quantities from columns F and G is given in the percent of the expected value. The shown quantities are provided for illustrative purposes only and may not represent the exact quantities.

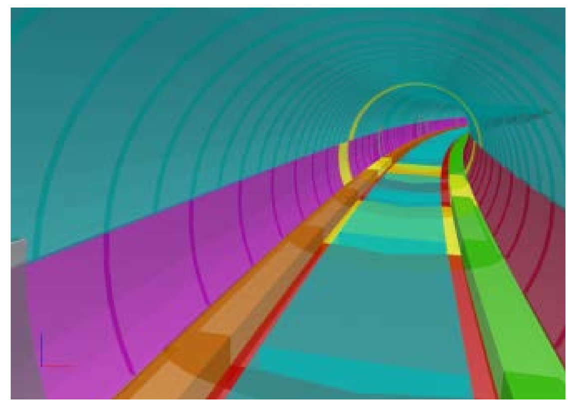

Figure 6: Karavanke tunnel as-built BIM model of primary support

3.5 THE PROCEDURE OF TESTING

The tests are imported into MatM program along with the BIM model and the bill of quantities.

The testing module is started which evaluates the quantities of each test on the data of imported BIM model. If there is a discrepancy between the expected and calculated value in a particular test, there could be three sources of errors, namely:

- errors in attribute data and/or geometry of the BIM model
- errors in element queries and evaluation formulae of BoQ pay items or tests
- errors in quantities of construction book

Through the testing we are able to spot and correct the errors in order to ensure the accuracy of attribute values in the constructed BIM models.

Additionally, we can ensure the correctness of element queries and evaluation formulae in the bill of quantities.

Yet another highly advantageous aspect of this testing methodology is its capacity that helps maintaining the correctness of attribute values between successive iterations of BIM model development. Test failures can indicate instances where, for example, recently resolved data processing issues have led to the presence of incorrect attribute values in sections of the model that were accurate in prior iterations.

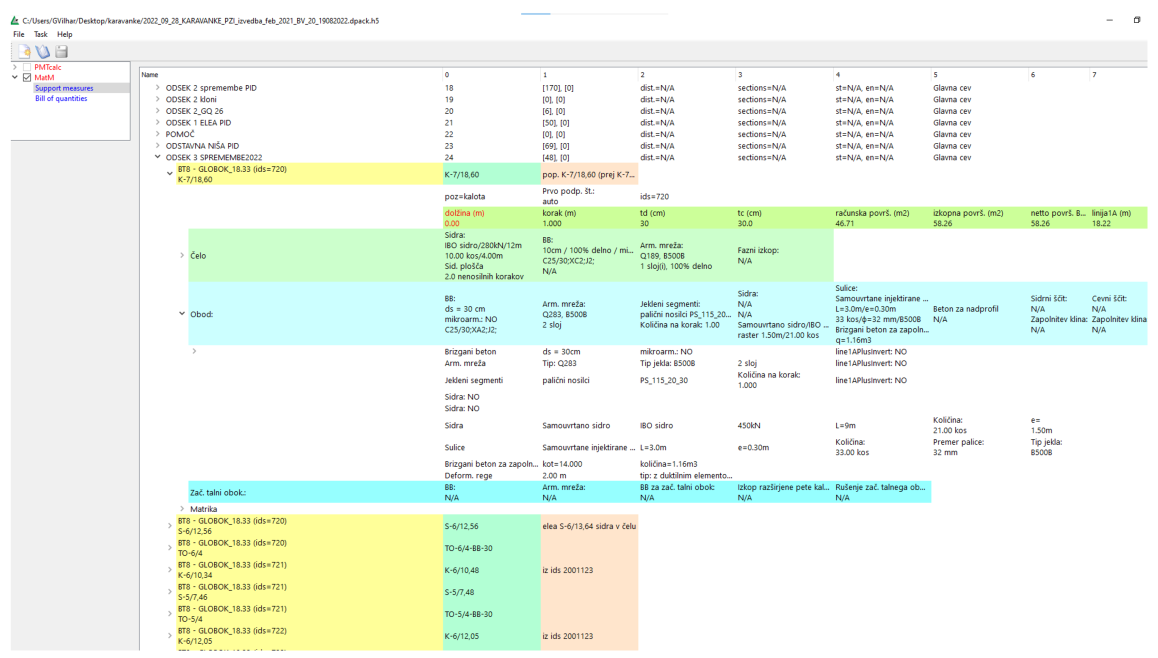

Figure 7: MatM program user interface for definition of support measures

4.2 EXAMPLE OF BIM DATA PLOTS ON THE VALIDATED BIM MODELS

A well-equipped, structured, and validated BIM model can serve as a rich database for conducting various data analyses, such as tracking construction progress.

Figure 1 illustrates the volume of conventional and fiber-reinforced shotcrete utilised in the tunnel's main tube for perimeter and face support plotted against the tunnel chainage. It is evident that the utilization of fiber-reinforced shotcrete commences at approximately chainage of 1750 meters.

The utilised mass of steel reinforcement of type Q189 and Q283 at the tunnel circumference and face is shown in Figure 2.

Figures 3 and 4 depict the application of rock bolts in the form of number of rock bolts and length of rock bolts along the tunnel's chainage.

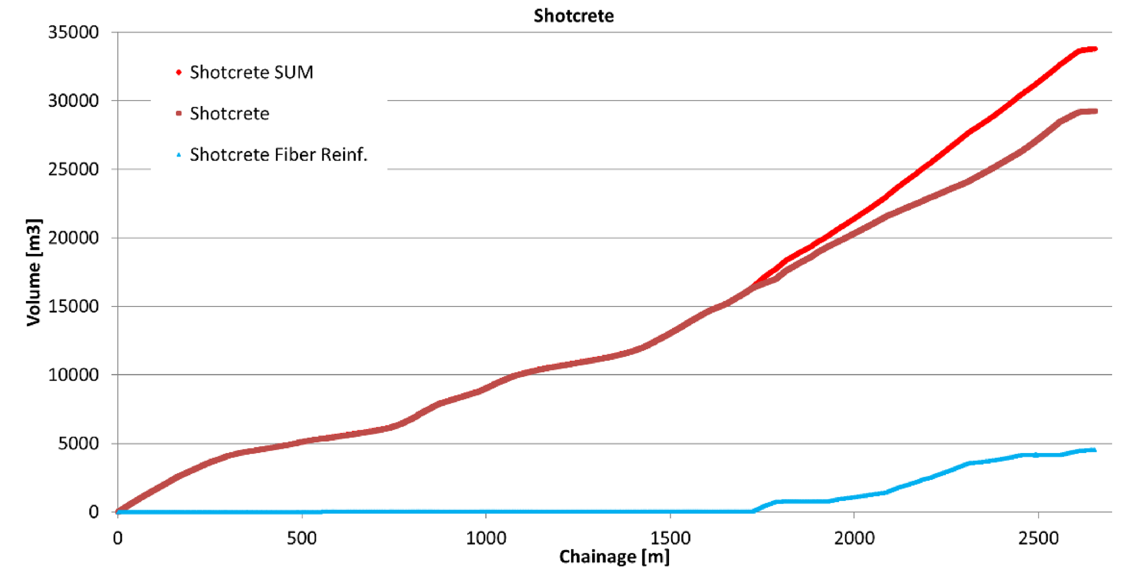

Figure 1: The cumulative volume of utilised shotcrete against the tunnel chainage plotted from Karavanke as-built BIM model. The volume of conventional shotcrete, fiber reinforced shotcrete and the sum of both types of shotcrete are plotted separately. The shown quantities are provided for illustrative purposes only and may not represent the exact quantities.

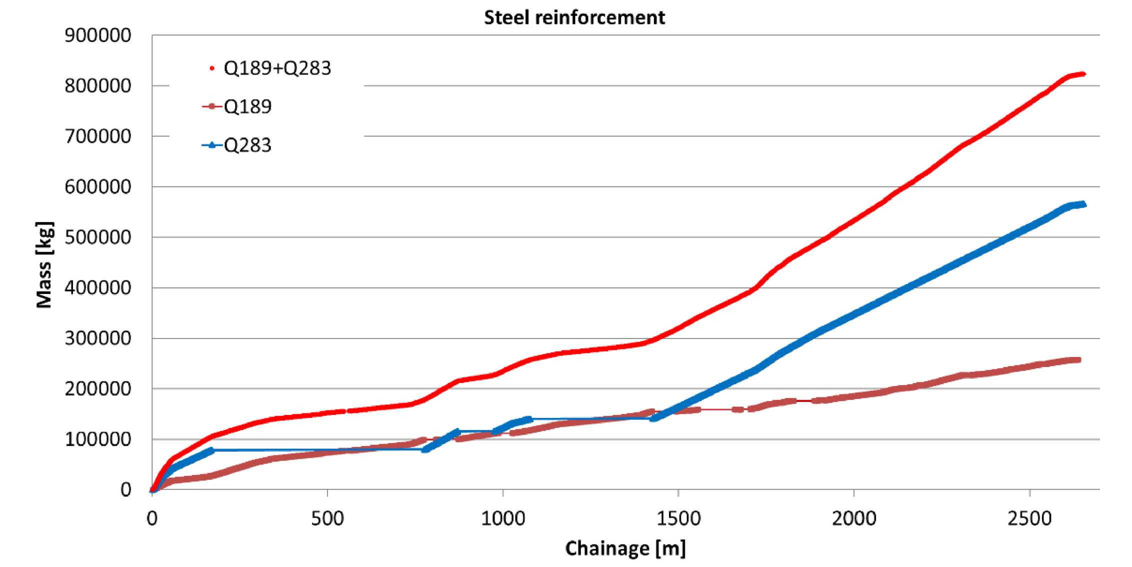

Figure 2: The cumulative mass of utilised steel reinforcement at tunnel circumference and face against the tunnel chainage. The data is extracted from the Karavanke as-built BIM model. The mesh types Q189 and Q283 are plotted separately along with the sum of both types. The shown quantities are provided for illustrative purposes only and may not represent the exact quantities.

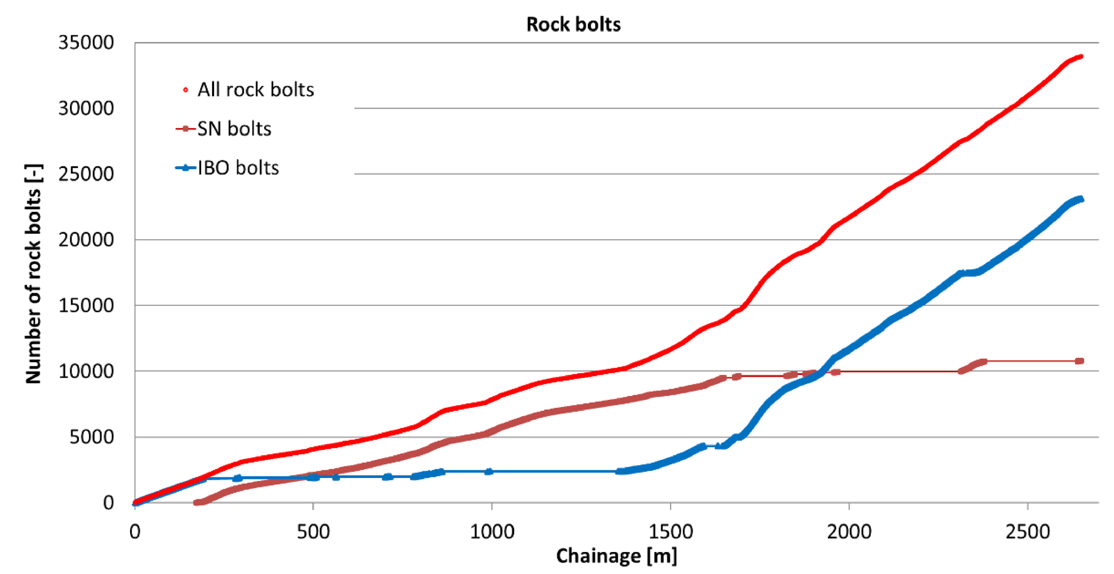

Figure 3: The cumulative number of utilised rock bolts against the tunnel chainage. The data is extracted from the Karavanke as-built BIM model. The shown quantities are provided for illustrative purposes only and may not represent the exact quantities.

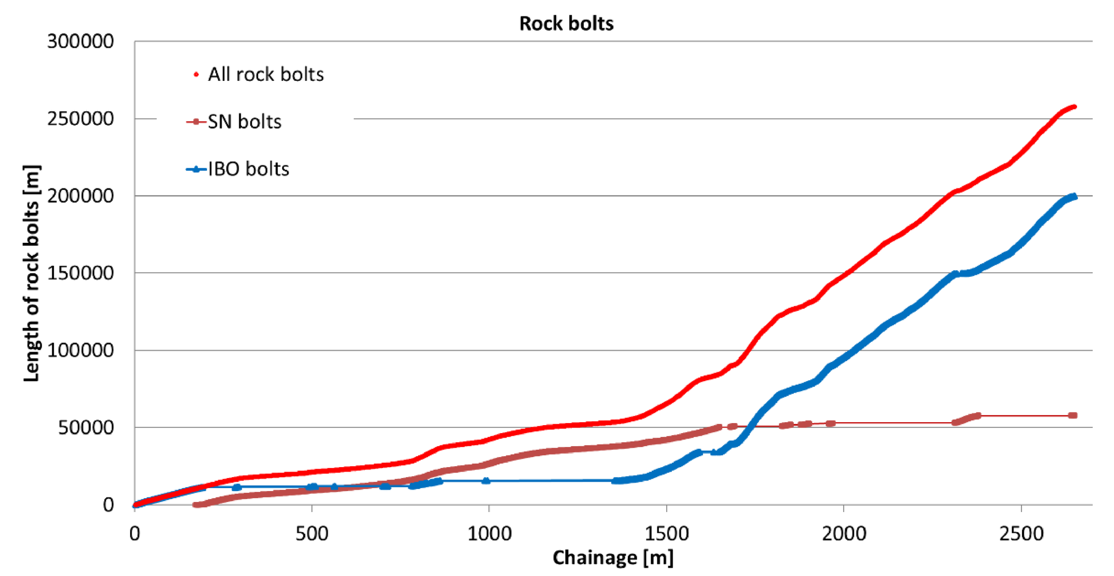

Figure 4: The cumulative length of utilised rock bolts against the tunnel chainage. The data is extracted from the Karavanke as-built BIM model. The shown quantities are provided for illustrative purposes only and may not represent the exact quantities.

5. CONCLUSIONS

A properly structured and thoroughly validated BIM model represents a rich database from which the data can easily be extracted and analysed in the form of quantity, time and cost.

As the as-built tunnelling projects progress, the amount of data stored in BIM models grows enormously. Hence, it's essential to implement effective methods for data management.

In this paper we present such methods in the form of additional functionalities of computer program MatM that have been developed at IRGO. They help us ensure the validity of quantities in the constructed BIM models.

By using MatM the BIM data can be validated through the automated tests that can be related to the bill of quantities.

As a use case the excavation/primary support as-built BIM model of Karavanke Eastern Tube tunnel has been presented.

MatM can be used to perform further data analyses on BIM model and generate the data for comparison plots which present useful monitoring overviews of the construction progress.

ACKNOWLEDGMENTS

The authors wish to thank all the contributors at Cengiz, DRI, Elea iC and IRGO Consulting for their work in preparing the Karavanke Eastern Tube excavation/primary support as-built BIM model.

REFERENCES

[1] ANDRICH W. (2022), DANIOTTI B., PAVAN A. and MIRARCHI C., "Check and validation of building information models in detailed design phase: A check flow to pave the way for BIM based renovation and construction", Buildings 2022, 12, 154, pp. 1-33

[2] Bexel Manager computer program, https://bexelmanager.com/

[3] VILHAR G. (2022), PEČOVNIK M., MUHIĆ E. and JOVIČIĆ V., "Implementacija BIM pristopa za spremljavo gradnje vzhodne cevi predora Karavanke", 15. Slovenski kongres o prometu in prometni infrastrukturi, Proceedings, Portorož (in Slovene)