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Verification and modification of the 5D BIM model carried out during bridge construction

Weryfikacja i modyfikacja modelu BIM 5D w trakcie budowy mostu

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Abstract. The main goal of the article is to describe the 5D BIM model of a post-tensioned concrete bridge being part of an expressway on the example of an ongoing construction. A method (a pattern) of monitoring of work progress as well as collecting the data (with relevant elements of coding of the collected data) and transferring it to the designers for the purpose of updating the model was developed while verifying the completed construction phases, the time schedule, the usage of materials and resources, including the expenses. The research confirmed incompatibility, also observed elsewhere in the construction sector, between the general contractor's and the designer's models . The article contains conclusions and practical examples of introducing the BIM methodology to design and construction of infrastructural objects while accounting for the construction site's realities.

Keywords: BIM; bridge construction; post-tensioned road bridge; 5D model.

Streszczenie. W artykule zaprezentowano model BIM 5D mostu kablobetonowego, usytuowanego w ciągu drogi ekspresowej, na przykładzie realizowanej budowy. Weryfikując etapy budowy, harmonogram robót, zużycie materiałów i zasobów, w tym koszty, opracowano schemat monitorowania postępu budowy, zbierania danych z ich odpowiednim kodowaniem oraz przesyłania projektantom w celu modyfikacji zaprojektowanego modelu BIM. Przeprowadzone badania potwierdziły, stwierdzone w wielu przypadkach kubaturowych modeli BIM, rozbieżności modeli BIM projektanta i wykonawcy. Artykuł zawiera wnioski i praktyczne wskazówki dotyczące wdrażania BIM do projektowania i budowy obiektów infrastrukturalnych uwzględniające realia budowy.

Słowa kluczowe: BIM; budowa mostu; kablobetonowy most drogowy; model 5D.

BIM *(Building Information Modelling)* comprises all the actions whose final outcome is development of a digital model of a facility containing multi-dimensional information [1]. Ten dimensions have already been defined in the course of development of the BIM methodology [1], with the first seven having been adapted to the needs of the construction process. The respective dimensions concern gathering of information about: geometry of the construction (items 1 – 3); implementation times and schedules (4); materials and costs (5); environmental impact (6); structure management after the construction phase (7).

The construction industry has been using BIM methodology to a large extent for a long time, often at the request of the clients, but also on the initiative of designers and general contractors. According to publications [2, 3] from 2021, the scope of BIM methodology use by Polish companies in various fields was as follows: buildings – 66.4%, roads – 11.2% and bridges – 7.8%. BIM software is mostly used during the design process – 55.2%, as compared to 20.7% in the case of construction works and construction supervision jointly, or 14.7% in the case of construction supervision only. The relatively low level of implementation of BIM methodology in infrastructure construction projects, at the construction phase in particular, results from the linear nature of such projects. Nevertheless, the activities of some ministries [4, 5, 6], GDDKiA, professional organizations (PZiTB, ZMRP), as well as projects such as CPK transport hub and the academic community itself stimulate and drive the implementation of the BIM methodology in infrastructure construction. BIM methodology is seen as an opportunity to streamline the process of designing, building and managing engineering facilities.

An increasing number of publications contain descriptions of pilot projects carried out by individual companies and people involved in the digitization of linear facilities. An important observation is that the designer's BIM model (developed before construction begins) often differs from the contractor's BIM model (i.e. the designer's model after modifications which take into account the actual conditions of construction and the contractor's requirements) [7]. The article describes the experience of a company which has been implementing the BIM methodology in building construction for a long time. For the needs of the infrastructure industry, the company is implementing a pilot BIM project based on the example of a contract for the design and construction of a section of the S1 expressway (EW) between Oświęcim and Dankowice [8].

Description of the facility and the developed BIM model

The subject of the pilot project is an engineering facility (MS-35) being part of EW S1 expressway which is located over the 4489S road, the Tesznowiec pond, the railway line No. 93 Trzebinia – Zebrzydowice, the planned access road and an underpass for medium-sized animals.

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The facility consists of two superstructures with variable geometry. The variation of geometry stems from the design requirements related to grade line, variable width of the deck slab, web spacing and its height.The structural diagrams of the load-bearing structures consist of ten-span, continuous, post-tensioned concrete box girders (Fig. 1 – 2, Table 1). Details of the design solutions can be found in [9, 10].

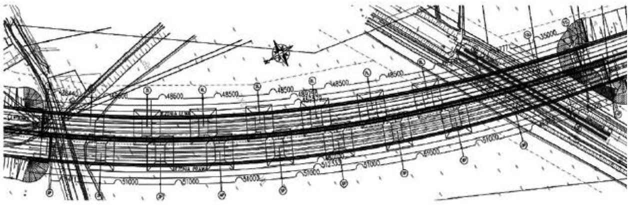


Fig. 1. Drawing showing the structure of the facility in top view [8]
Rys. 1. Schemat konstrukcji obiektu w widoku z góry [8]

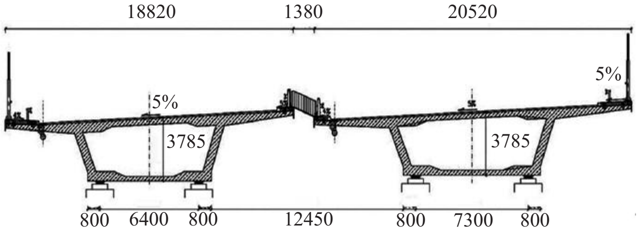


Fig. 2. Example of the cross-section of the supporting structure [8]
Rys. 2. Przykładowy przekrój poprzeczny konstrukcji nośnej [8]

Table 1. Selected facility parameters [8]
Tabela 1. Wybrane parametry obiektu [8]

Element	MS-35 (left roadway)	MS-35 (right roadway)
Total bridge length [m]	463,312	482,700
Theoretical length of spans [m]	38,44 + 7 x 48,50 + 47,77 + 35,00 = 460,71	41,13 + 7 x 51,00 + 46,97 + 35,00 = 480,10
Total bridge width (max.) [m]	18,70 + 1,30 (gap between decks) + 20,60 = 40,60	
Construction height [m]	4,033	3,703
Deck width [m]	16,80 – 18,70	16,80 – 20,60

Due to the geometry and unfavourable location of the facility, two design approaches were chosen. A classic one, with 2D documentation, and an approach involving a BIM model *(Tekla Structures program)*. Parameters related to time (4D) and costs and materials (5D) were introduced into the geometric model (3D). The main goal of the pilot project is to determine the usefulness of the multidimensional BIM model at various stages of the construction project's implementation and to develop internal standards which will be useful in subsequent projects. Construction of residential/commercial/industrial buildings, in which the company already has experience with using BIM technology, differs from infrastructure construction, rendering it impossible to standardize all the solutions which are already in use. During the work on the BIM model, differences between individual industries became apparent. Those differences affected the nature of the digital object. The most important is the complex geometry of bridge structures resulting from a diversified road route being combined with the superstructure which is built in stages while using various technologies.

Designer's BIM model. All elements of the facility were modelled in the designer's BIM model – from the piles underneath the foundations through the load-bearing structure with reinforcement to the equipment. For various reasons, some elements such as the excavation volumes which were set with reference to the average ground level, were modelled in a simplified manner. One of the uses of the BIM model at construction sites is to control the pace of work. Therefore, the data from the work schedule have been added to each element. This has enabled easy and quick verification of the actual and assumed progress of construction works while using the BIM model (Fig. 3).

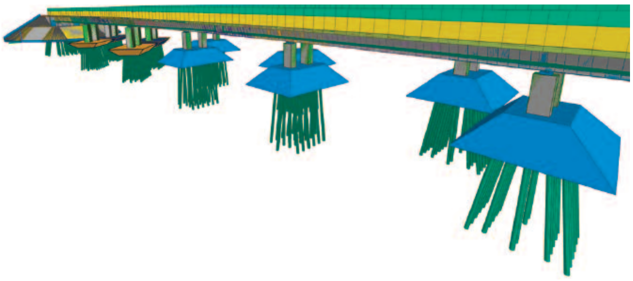
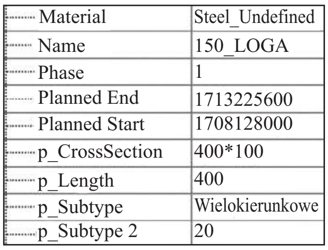


Fig. 3. BIM model – fragment of the model with the view of the southern abutment (P12)
Rys. 3. Model BIM – fragment modelu z widokiem na przyczółek południowy (P12)

What is important from the point of view of the entire project is the dimension related to costs and materials. The model has been saturated with information enabling semi-automatic generation of bills of materials and cost estimates. In order to ensure the correct data flow, appropriate codification and parameterization of elements was adopted.

In order to ensure the uniqueness of the elements, which are assigned to bill of quantities items, a coding system, based on 3 digits, an underscore and 4 letters according to the „999_ABCD" pattern, has been introduced. This enabled the initial segregation of elements according to material or manufacturing technology. The next step was to parameterize the elements, which made further filtering of the model's components easier. Due to the great diversity of the facility's components, its cost estimate contains many items relating to various materials. In order to systematize the data matrix, their segregation was implemented in a form which is friendly to users and counting programs. The following are the examples which require additional codification:

- in the case of excavations, each solid representing an excavation in the ground has a subtype (parameter) that allows one to choose between excavation in rocky or non-rocky soil;
- in the case of cup bearings, two parameters defining the subtype were used. The first defines whether the bearing is fixed, uni-directionally slidable or multi-directionally slidable. The second one contains the information about the load range given in MN, enabling the determination of the bearing load capacity (Fig. 4);



Material	Steel_Undefined
Name	150_LOGA
Phase	1
Planned End	1713225600
Planned Start	1708128000
p_CrossSection	400*100
p_Length	400
p_Subtype	Wielokierunkowe
p_Subtype 2	20

Fig. 4. Example of coding and description of the pot bearing parameters
Rys. 4. Przykład kodowania – opisu parametrów łożysk garnkowych

- in the case of coding of concrete elements, in addition to indicating the specific structural element, such as a foundation, an abutment or a superstructure, three parameters were added which define the concrete class, the exposure class and the element reinforcement index.

The adopted codification enabled precise description of the billed elements, their segregation and filtration, both at the level of the model itself as well as at the level of the cost estimate.

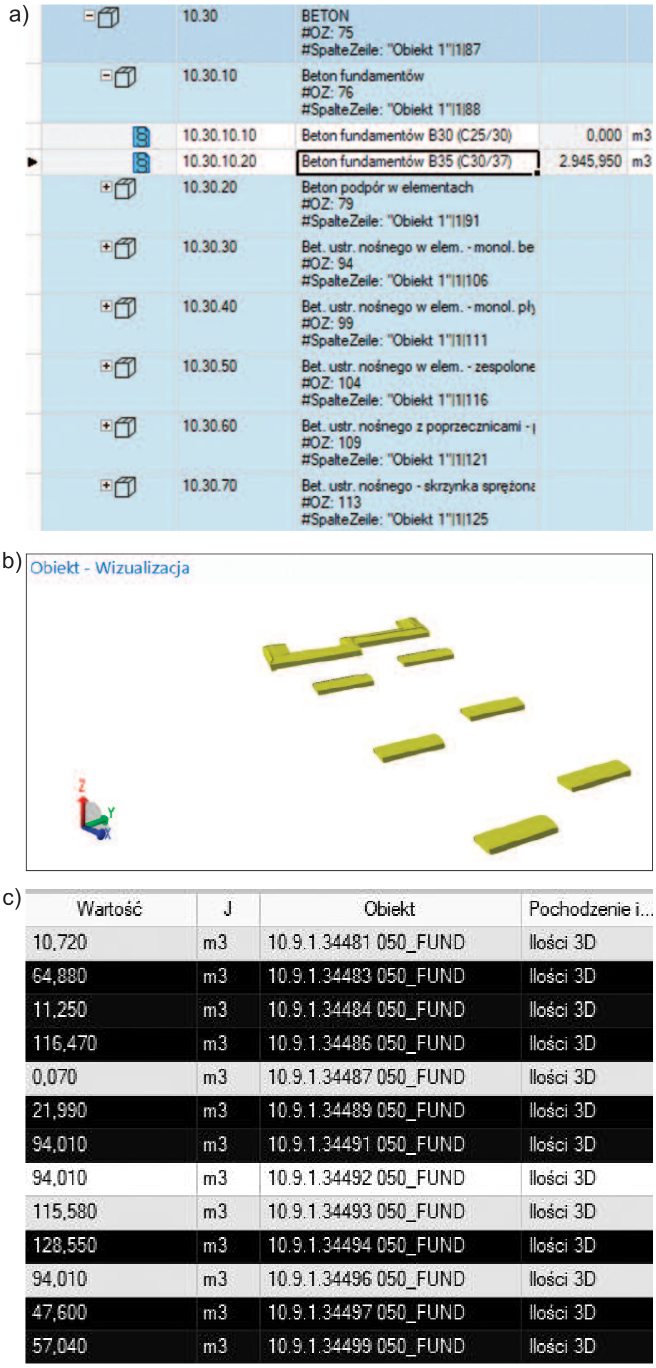
From the contractor's point of view, the most important aspect of the 5D dimension is the ability of quick generation of cost estimates and bills of materials in order to verify and prepare orders at the construction site. By comparing data from the BIM model and the construction site, one can quickly determine possible discrepancies. The open IFC data format, which was imported into the iTWO5D software used at the design stage, has been employed in order to ensure efficient access to BIM model data.The adopted codification and parameterization system and the appropriate formulas of the iTWO5D program enabled creation of a data matrix which matched the elements of the BIM model to the bill of quantities items. Fig. 5 illustrates the incorporation of information in the model and its location in the bill of quantities.Thanks to the introduction of the matrix into the iTWO5D program, each subsequent change in the model version could be calculated automatically after loading it into the program.

Data collection at construction site and modification of the BIM model

The iTWO5D software and the CDE platform are based on cloud solutions, therefore an efficient Internet connection is required to use these systems. It may be difficult to provide a connection with sufficient capacity at the infrastructure construction sites. That is why a decision was made to use an offline solution. It was assumed that the BIM Vision program would be used at the construction site along with proprietary plug-in developed by the company team. The main task of this plug-in is to connect the IFC models with an Excel spreadsheet. By using this tool, the staff at the construction site can continuously verify the amount of materials planned for installation and actually used. Data collected from the construction site can be systematically compared, both with the data obtained from the BIM model and with traditional documentation, thus simultaneously enabling analysis of the accuracy of BIM models in relation to traditional documentation. As the construction project is ongoing, hence only sample data, illustrating the effects of the procedure regarding several elements, are quoted below:

- ■ foundations of supports under the P1 abutment and the supports P2 and P3 (Table 2);
- ■ pillars of the support P2 (Table 3);
- ■ front wall of the P1 abutment (Table 4);
- ■ non-structural concrete under the supports P2 and P3 (Table 5).

The following system of markings has been adopted in tables 2-5: PXL/PXP – a support in the X axis on the left/right side with increasing mileage; PXWL/PXZL – internal pillar (closer to the main route axis)/outer supports in the X axis on the left side with increasing mileage – similarly for the right side.



a)

10.30	BETON #OZ: 75 #SpalteZeile: "Obiekt 1"|1|87		
10.30.10	Beton fundamentów #OZ: 76 #SpalteZeile: "Obiekt 1"|1|88		
10.30.10.10	Beton fundamentów B30 (C25/30)	0,000	m3
10.30.10.20	Beton fundamentów B35 (C30/37)	2.945,950	m3
10.30.20	Beton podpór w elementach #OZ: 79 #SpalteZeile: "Obiekt 1"|1|91		
10.30.30	Bet. ustr. nośnego w elem. - monol. be #OZ: 94 #SpalteZeile: "Obiekt 1"|1|106		
10.30.40	Bet. ustr. nośnego w elem. - monol. pły #OZ: 99 #SpalteZeile: "Obiekt 1"|1|111		
10.30.50	Bet. ustr. nośnego w elem. - zespolone #OZ: 104 #SpalteZeile: "Obiekt 1"|1|116		
10.30.60	Bet. ustr. nośnego z poprzecznicami - ¦ #OZ: 109 #SpalteZeile: "Obiekt 1"|1|121		
10.30.70	Bet. ustr. nośnego - skrzynka sprężona #OZ: 113 #SpalteZeile: "Obiekt 1"|1|125		

b)

c)

Wartość	J	Obiekt	Pochodzenie i...
10,720	m3	10.9.1.34481 050_FUND	Ilości 3D
64,880	m3	10.9.1.34483 050_FUND	Ilości 3D
11,250	m3	10.9.1.34484 050_FUND	Ilości 3D
116,470	m3	10.9.1.34486 050_FUND	Ilości 3D
0,070	m3	10.9.1.34487 050_FUND	Ilości 3D
21,990	m3	10.9.1.34489 050_FUND	Ilości 3D
94,010	m3	10.9.1.34491 050_FUND	Ilości 3D
94,010	m3	10.9.1.34492 050_FUND	Ilości 3D
115,580	m3	10.9.1.34493 050_FUND	Ilości 3D
128,550	m3	10.9.1.34494 050_FUND	Ilości 3D
94,010	m3	10.9.1.34496 050_FUND	Ilości 3D
47,600	m3	10.9.1.34497 050_FUND	Ilości 3D
57,040	m3	10.9.1.34499 050_FUND	Ilości 3D

Fig. 5. Example of a bill of materials prepared while using the iTWO5D program; a) list of model elements matched to the take-off items; b) visualization of the model's elements from the indicated take-off item; c) bill of materials for the individual elements shown in the visualization

Rys. 5. Przykład zestawienia materiałów za pomocą oprogramowania iTWO5D: a) zestawienie elementów modelu dopasowanych do pozycji przedmiarowych, b) wizualizacja elementów modelu ze wskazanej pozycji przedmiarowej, c) zestawienie ilości materiałów w poszczególnych elementach widocznych na wizualizacji

Based on the data contained in Tables 2-5, it was found that construction works were significantly ahead of the work schedule – some elements were completed from a month to even as much 2.5 months ahead of the planned date.With regard to material consumption, the findings were as follows:

Table 2. List of planned and actual dates and consumption of materials for the construction of support foundations
Tabela 2. Zestawienie planowanych i rzeczywistych terminów oraz zużycia materiałów podczas wykonania fundamentów podpór

Pillars foundations								
Element	planned date		actual date		usage of material			
	start	end	start	end	material	planned (P) [m^3]	actual (A) [m^3]	A/P [%]
P1L	17.01.2023	13.02.2023	09.01.2023	09.01.2023	C30/37	285,76	283,00	99
P1P	17.01.2023	13.02.2023	23.12.2022	23.12.2022	C30/37	348,99	356,00	102
P2L	27.02.2023	18.03.2023	25.01.2023	25.01.2023	C30/37	94,01	94,50	101
P2P	27.02.2023	18.03.2023	13.01.2023	13.01.2023	C30/37	94,01	96,50	103
P3L	20.03.2023	08.04.2023	02.02.2023	02.02.2023	C30/37	94,01	129,00	137
P3P	20.03.2023	08.04.2023	09.02.2023	09.02.2023	C30/37	94,01	114,00	121

Table 3. List of planned and actual dates and consumption of materials for the construction of supports (pillars)
Tabela 3. Zestawienie planowanych i rzeczywistych terminów oraz zużycia materiałów podczas wykonania podpór (filarów)

Pillars foundations								
Element	planned date		actual date		usage of material			
	start	end	start	end	material	planned (P) [m^3]	actual (A) [m^3]	A/P [%]
P2WL	20.03.2023	25.03.2023	16.02.2023	16.02.2023	C35/45	12,84	14,50	113
P2ZL	20.03.2023	25.03.2023	20.02.2023	20.02.2023	C35/45	12,84	15,00	117
P2WP	03.04.2023	17.04.2023	01.03.2023	01.03.2023	C35/45	15,29	16,50	108
P2ZP	03.04 2023	17.04.2023	24.02.2023	24.02.2023	C35/45	15,29	17,50	114

Table 4. List of planned and actual dates and consumption of materials for the construction of the front wall abutment P1
Tabela 4. Zestawienie planowanych i rzeczywistych terminów oraz zużycia materiałów podczas wykonania ściany czołowej przyczółka P1

Abutment front wall								
Element	planned date		actual date		usage of material			
	start	end	start	end	material	planned (P) [m^3]	actual (A) [m^3]	A/P [%]
P1L	07.02.2023	18.03.2023	01.02.2023	01.02.2023	C30/37	293,24	234,50	80
P1P	07.02.2023	18.03.2023	18.01.2023	18.01.2023	C30/37	329,11	265,00	81

- foundations – in the case of the P1 abutment and P2 support, material consumption was nearly 100% on target, while deviation of 20-40% occurred in the case of the P3 support. Elements with such simple geometry (Fig. 6) should not demonstrate such big deviations. The reason for this was the introduction of design modifications in the foundation area already after creation of the model and failure to update the model subsequently;

Table 5. List of planned and actual dates and consumption of materials for the construction of non-structural concrete supports
Tabela 5. Zestawienie planowanych i rzeczywistych terminów oraz zużycia materiałów podczas wykonania betonu niekonstrukcyjnego podpór

Non-structural concrete supports								
Element	planned date		actual date		usage of material			
	start	end	start	end	material	planned (P) [m^3]	actual (R) [m^3]	A/P [%]
P2L	27.02.2023	18.03.2023	03.01.2023	03.01.2023	C12/15	11,16	14,00	125
P2P	27.02.2023	18.03.2023	03.01.2023	03.01.2023	C12/15	11,16	14,00	125
P3L	20.03.2023	08.04.2023	24.01.2023	24.01.2023	C12/15	11,16	22,00	197
P3P	20.03.2023	08.04.2023	31.01.2023	31.01.2023	C12/15	11,16	17,00	152

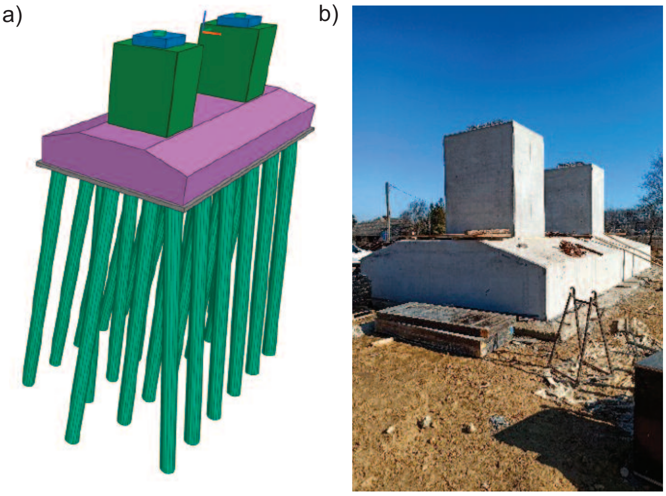


Fig. 6. An example of a completed support presented on axis 2: a) an element of the BIM model of the support under the left roadway; b) the actual support
Rys. 6. Przykład wybudowanej podpory w osi 2: a) element modelu BIM podpory pod lewą jezdnią; b) podpora rzeczywista

- support pillars in axis 2 – the difference was 8 – 17%, which was considered acceptable;
- front wall of the P1 abutment – the amount of material used was 20% less than predicted in the model. This was due to the division of the model into parts that were easier to modelbut which did not correspond to the concreting stages in all cases;
- non-structural concrete of the P3 support – much greater consumption than expected (design change not included in the model).

In addition to the data regarding the amount of the materials used (built-in) and the schedule of manufactured elements, the model is expected to be enriched with information on material cards, design revisions and occurring faults. For this purpose a program called Plan Radar [1] was employed which is successfully used in building construction to support engineering staff on site.

An iterative procedure diagram was designed (Fig. 7), which takes into account construction staging and schedule, as well as specifies the set of data (information) transferred

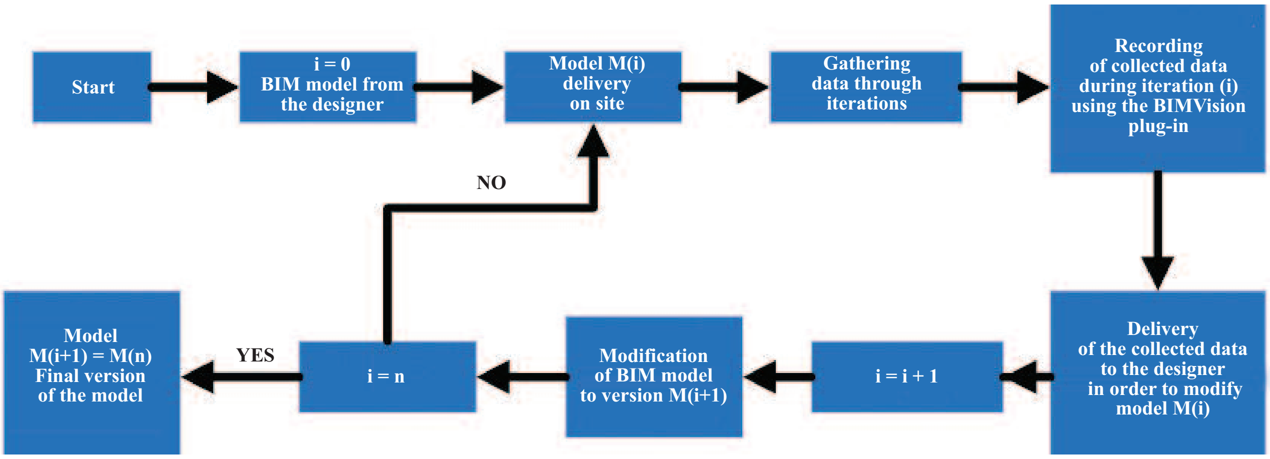


Fig. 7. Scheme of transferring of the information from the construction site for the purpose of modifying the BIM model
Rys. 7. Schemat przesyłania informacji z budowy w celu modyfikacji modelu BIM

from the construction site to the BIM model designer for the purpose of updating the model. Subsequent versions of BIM models (marked as M(i), i = 0 to n) will be created during subsequent iterations of model modification, with M(0) – the designer's initial model, M(i) – the modified model after the i-th iteration, M(n) – the last variant of the contractor's model.

Summary

Based on the research conducted, the following conclusions have been formulated, following the pilot implementation of the BIM methodology during the construction of a post-tensioned concrete bridge:

1) research confirmed the discrepancies between the BIM model developed by the designer (the model before construction) and the contractor's model (the model which was modified to take into account construction realities), which were found in many cases of BIM models of building constructions;

2) verification of the initial stages of construction revealed discrepancies and deviations from the design, in particular regarding:

■ schedule of implementation of the early stages of work – works being completed ahead of the planned dates;

■ material consumption - discrepancies occurred due to:

– no model update to the latest version of the design – due to the frequency of design changes during the construction of the facility, model updates were postponed,

– simplification of the geometry of elements and methods of generating elements in combination with the staging of works;

– the conditions encountered at the construction site differing from those expected,

3) collecting of data (information) from the construction site and updating the model, in the previously indicated scope (in the designer's BIM model), requires appropriate workload and appropriate staff with know-how in the fields of model management and BIM methodology;

4) it is necessary to develop the IFC *(Industry Foundation Classes)* data format dedicated to infrastructure construction, which will enable efficient import and export of data from native programs (in this case the IFC 2x3 format dedicated to construction of buildings was used);

5) optimal implementation of the BIM methodology at the construction site requires appropriate technical infrastructure with a fast Internet connection on site.

To sum up, an increase in the transparency of the collected data was found, from the design stage to the implementation stage. Access to already prepared information and the process of collecting of the current construction data have been simplified.

Final conclusions from the pilot project will be available after its completion. However, the experience already collected will be useful in relation to the upcoming deadline for mandatory use of the methodology in selected public procurement proceedings.

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