

# Utilization of BIM for automation of quantity takeoffs and cost estimation in transport infrastructure construction projects in the Czech Republic

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**Abstract.** The article deals with problematic parts of automated processing of quantity takeoff (QTO) from data generated in BIM model. It focuses on models of road constructions, and uses volumes and dimensions of excavation work to create an estimate of construction costs. The article uses a case study and explorative methods to discuss possibilities and problems of data transfer from a model to a price system of construction production when such transfer is used for price estimates of construction works. Current QTOs and price tenders are made with 2D documents. This process is becoming obsolete because more modern tools can be used. The BIM phenomenon enables partial automation in processing volumes and dimensions of construction units and matching the data to units in a given price scheme. Therefore price of construction can be estimated and structured without lengthy and often imprecise manual calculations. The use of BIM for QTO is highly dependent on local market budgeting systems, therefore proper push/pull strategy is required. It also requires proper requirements specification, compatible pricing database and software.

## 1. Introduction

Transport infrastructure construction projects are one of widely debated topics in public discussion. There has been substantial discontentment with both quality and costs of new construction works or repairs of current roads and motorways. The costs of such construction projects or future maintenance costs can be influenced primarily in pre-investment and investment phase [1]. That is a good reason to pay detailed attention to these phases of project life cycle. It is in the best interest of any investor to know the costs of construction project in as much detail as needed, in order to make economically sound decisions concerning the development of construction work. When we compare construction to other branches of industry, it is rather specific because every construction work is a unique product. Therefore, it is difficult to estimate construction costs very precisely from design. Even with the latest tools, it is next to impossible to reach a perfect match of real and estimated costs of construction. Real costs are obvious only after the project is finished. But there are methods of bringing the real and estimated costs closer together. Building Information Modeling (BIM) is one of them. This paper deals with current options of using a BIM model for quantity takeoffs in the Czech Republic (CR) and connecting this model with public price databases of Directorate of Highway and Motorway in CR (DHM).



Current system of estimating price in Czech construction companies is highly labour-intensive and there is much room for error. Making quantity takeoffs from 2D documentation, which is still very common, is obsolete when compared to modern tools. The reasons for using inadequate methods are many, and they are not specific only to the CR – it can be inadequately prepared legislation or incompatibility of model and price system.

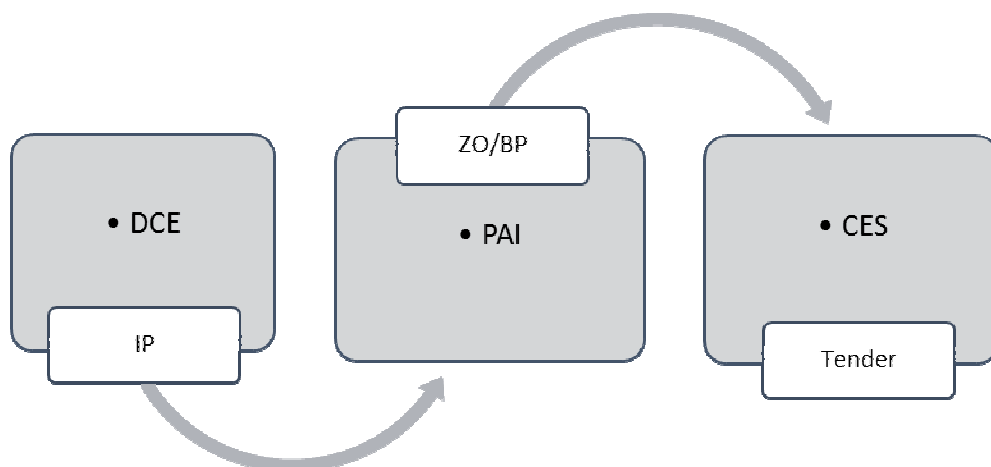
## 2. Estimated costs of transportation infrastructure in the CR

The method of estimating costs of transportation infrastructure projects in the CR depends on the phase of investment process, i.e. the level of detail given in entry data for estimation. There are four different phases of project documentation, all being parts of the investment and legislative procedure which leads up to a building permit.

In the first phase (project beginning), the estimated cost of construction is stated in the investment plan (IP), it is established according to Database of cost estimate (DCE). DCE establishes so-called base cost of realizing individual construction objects (tunnels, groundwork, etc.). Base cost always responds to criteria of Czech National Standards, and can be modified by so-called expert modification, which only serves for conforming the norms to situation in construction zone. The process of estimating total cost of investment plan is listed here:

- major construction objects are estimated according to database of base costs,
- other construction objects are estimated according to percentual rates,
- base costs are modified, if needed,
- risk assessment for all construction objects is carried out,
- total price estimate for investment plan is finalized, possible conversion to current price system. [2]

When the investor authorizes the investment plan, project documentation is prepared for Zoning (ZO) and Building permit (BP). Certified public institution issues these documents. The estimated price during this phase follows Proceedings of aggregated items for valuation of construction (PAI). PAI delimits major categories of construction object, construction costs of each category represent 80 % and more out of the total investment cost. These are motorways, roads, bridges, tunnels, walls, sewage, water conduit, gas conduit, tanks, noise protection, fencing (including subcategories of new construction and reconstruction for motorways, roads and bridges). The process (see Figure 1) of estimating total costs during ZO and BP is similar to the process of estimating the investment plan, only the databases differ in each phase.



**Figure 1.** Estimate data and different databases used for estimate in phases of investment process (source: authors).

When a certified institution issues a permit for realization of construction work, drafts of competition are created, in order to choose general contractor. Then the most detailed estimate follows, one that is based on Classification of Engineering Structures (CES). CES specifies the standard of transport constructions in great detail, and also products needed to reach standard quality of construction. CES enables the estimator to compile a quantity takeoff according to the character of construction, and the contractor's demands regarding estimation process. Quantity takeoff defines all contractor's demands – estimate of required amounts of work, supplies and services. It gives full information about types and amounts of supplies and services, therefore it is used as input for subcontractors' offers. The takeoff states manner of estimation of construction works, as defined by a specific list of prices and tariffs. CES is a summary of all individual construction objects paired with proper code, description, unit of measure, and unit price. Unit price within CES is called „expert price“. The total price estimated with use of CES is considered the most precise estimate possible. Figure 1 summarizes the whole process – from estimate of investment plan making use of DCE to the final estimate of contracting documentation based on CES [3].

### 3. Quantity takeoff and BIM

Quantity takeoff is a list of individual construction units as taken from project documentation. It states the required amounts of work, constructions, supplies and services rendered in units of measure. It is expected to be well arranged, structured and revisable [4]. In case of transport infrastructure construction projects, a supplier is contracted by Directorate of Highway and Motorway in CR (DHM) or Ministry of Transport. This engineering company creates quantity takeoff and creates all project documentation for all phases of the investment process.

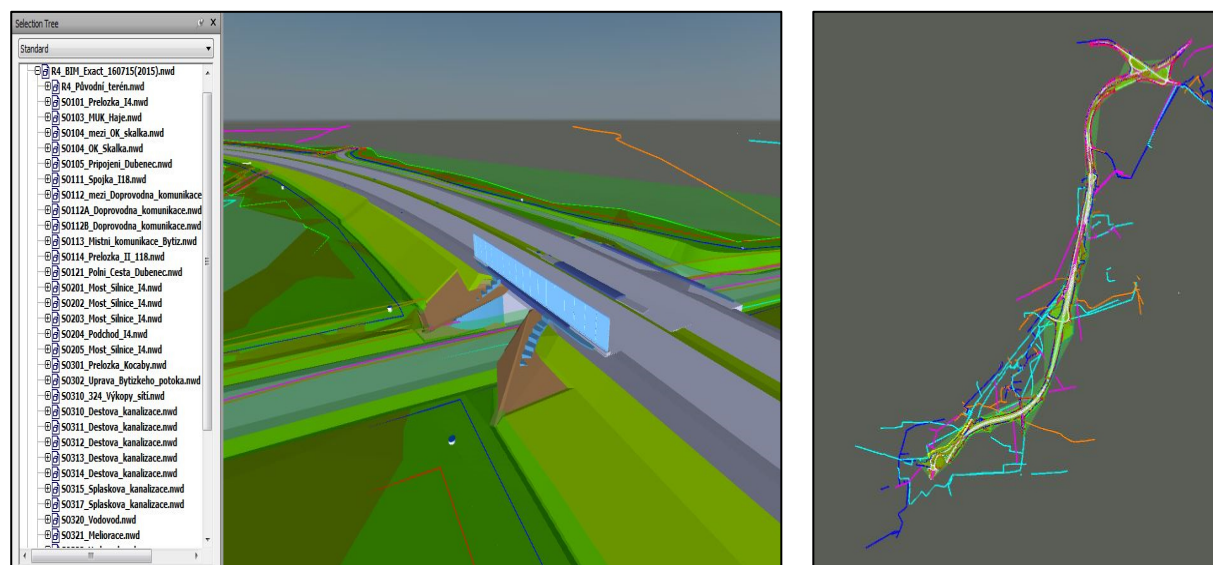
Estimator creates quantity takeoff and estimation of construction work (from IP to drafts of competition). Estimator is a specialized profession in civil engineering, expert who reads individual quantities of construction work as defined in project documentation and classifies them using a given database (DCE, PAI, CES) [5].

A large part of BIM model is made up of databases, which allow extracting information. Quantity takeoff may be one way of extracting information from a BIM model. It can also be varied in level of detail. The creator of information is also the creator of BIM model but the level of detail within the model can vary and ought to be specified in contract. Standard model requirements specify creating a model in one of the phases of project documentation, mostly there is no need to link the information in the model with a specific price estimate system. If BIM model is created with all the additional data to enable price estimate, it results in extrawork, and the price of such detailed model rises. However, most models already contain large amounts of data needed for price estimates. Unfortunately, these models are often incomplete, created by different contractors, and construction estimator is not supplied with the entire model, only its exported output (e.g. IFC or NWD). This leads to unfavourable loss of information. Construction estimator should specify requirements for additional information, so that model data can be used efficiently, especially when it concerns measurements of construction objects in BIM model. Such specification may be a part of model requirements stated in construction contract.

When BIM model is efficiently linked to cost estimate system via partially automated quantity takeoff, the estimator's role in the process is significantly simplified. Estimator ceases to be the creator of quantity takeoff, rather he becomes quantity takeoff reviewer. Estimator may use BIM model for reference and additional calculations – such that cannot be automated or are not part of model.

### 4. BIM model analysis with regard to quantity takeoffs

Due to current situation in transport infrastructure in the CR, there have not been many BIM-based models so far. Investment in BIM model is not supported, the contractors need to use their own resources to pay for BIM model. For the purpose of the research, models from Skanska AB were used. These models were originally used for different purposes than quantity takeoffs, namely for visualising and coordination. Skanska has offered several models for analysis (see Figure 2).



**Figure 2.** Layout drawing of motorway D4 in BIM (source: Skanska).

Models have been analyzed from two viewpoints. Analysis of model objects has been done to verify that the model contains necessary data for measurements or required information as such. The second aspect of analysis was the possibility to match individual objects and specific work or one unit of CES. Autodesk Naviswork Manage (further referred to as Navisworks) was used to create CES quantification workbook structure, as shown in Figure 3.

Items		WBS
+	VŠEOBECNÉ KONSTRUKCE A PRÁCE	0
+	ZEMNÍ PRÁCE	1
+	ZÁKLADY	2
+	SVISLÉ KONSTRUKCE	3
+	VODOROVNÉ KONSTRUKCE	4
+	KOMUNIKACE	5
+	ÚPRAVA POVRCHŮ, PODLAHY, VÝPLNĚ OTVORŮ	6
+	PŘIDRUŽENÁ STAVEBNÍ VÝROBA	7
+	POTRUBÍ	8
+	OSTATNÍ PRÁCE	9

**Figure 3.** CES quantification workbook structure adapted to BIM software (source: authors using Navisworks).

Objects in BIM model have been classified. Analysis, which followed, showed that exported models, currently created for use in the CR, do not contain necessary information, not even for partial automation of quantity takeoff. The major reason for this situation is that models are passed via IFC or NWD format for use in Navisworks. Original model information is lost in the process because it is not considered necessary for coordination. Moreover, the medium does not enable recovery of data. The second important reason for data losses is high degree of aggregation of objects contained in a model. Road as an object is not differentiated in its partial levels.

Current state of models allows for price estimate only in the beginning phases of investment process. DCE and PAI allow us to generate quantity takeoff, making use of integrated software tools. Unfortunately, full automation is currently impossible.

## 5. Case studies

For the purpose of the research, the consistency of the theoretical findings and practice has been examined on two case studies.

### 5.1. D4 (Skalka) motorway

The first case study focuses on the completion of a nearly five kilometre section of D4 motorway (Skalka) in the Central Bohemian Region. It is the first transport infrastructure project in Czech Republic, where the contractor uses the BIM model during construction. Specifically, it is the construction of multilevel intersection of D4 motorway with road II/118 nearby Háje municipality and the construction of a new supporting II. class road. Table 1 shows basic information about the construction.

**Table 1.** Basic information about completion of D4 motorway (source: [7]).

Beginning of construction	04/2014	Opening	09/2017
Length of road	4 788 m	Time of construction	2 years
Term of guarantee	120 months	Winning bid	417 485 287 CZK

### 5.2. D1 (Přerov – Lipník nad Bečvou) motorway

The second case study focuses on the construction of 14 kilometres long section of D1 motorway between towns Lipník nad Bečvou and Přerov in Olomouc Region. There will be 24 bridge structures, 3 multilevel intersections and over 7 noise barriers or support walls. The construction of the new section of D1 includes, in addition to the main route, the relocation of I.-III. class roads and paths in total length of almost four kilometers [8]. Table 2 shows basic information about the construction.

**Table 2.** Basic information about construction of new D1 motorway section (source: [9]).

Beginning of construction	08/2015	Opening	08/2018
Length of road	14 300 m	Time of construction	2 years
Term of guarantee	120 months	Winning bid	2 717 043 775 CZK

### 5.3. Case studies conclusion

The main use of BIM model in both cases is mainly for guidance of GNSS guided construction machinery for excavation and laying works. Unfortunately, information models were not used to generate quantity takeoffs of individual construction works [6, 8].

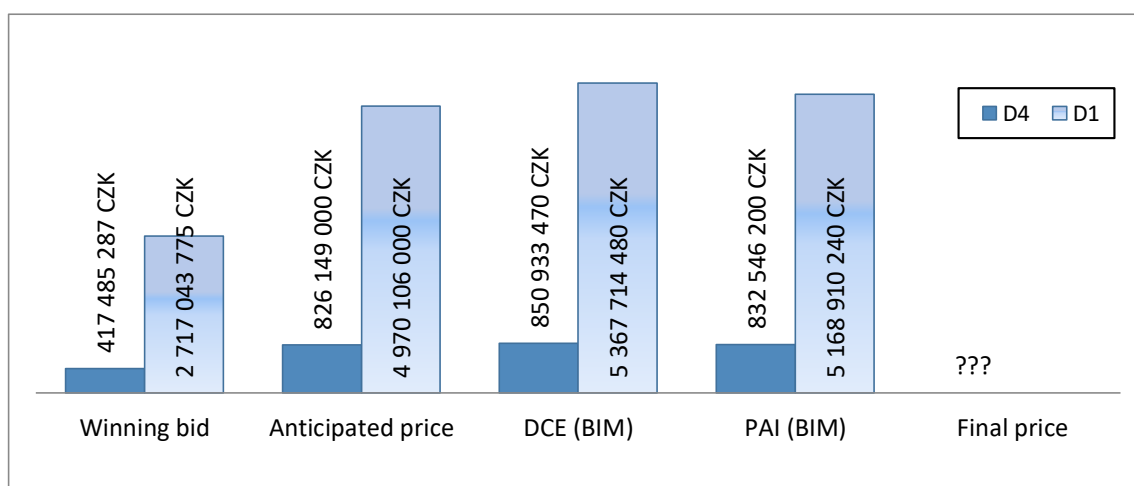
Winning bid for this stretch of highway is roughly fifty per cent lower than original estimate made according to CES. Price tendering in the range of 50 to 70 % of the presumed price, determined with the use of CES, represents the current situation in the Czech infrastructure construction projects. The possible sources of difference between corporate and CES prices from CES technical perspective may be (especially, but not exclusively):

- different profit rates (CES calculates with higher profit rates),
- achievable rebates for the purchase of building materials (corporate prices are lower),
- lower machines costs, when compared to CES (machines are used even when already depreciated).

Other possible market and economical sources are not mentioned. It is important to state that such sources might even be marginal when compared to those mentioned. To identify these other sources, further and more thorough analysis is necessary. Such analysis is not part of this paper.

Further difference between unit prices in cost estimate systems is caused by quantity discounts in case of construction material purchases made by large companies. Building machinery costs in price estimate systems also count on depreciation costs. When the machinery is already depreciated, machinery costs are lowered to mere operating costs. The difference is also aggravated by use of different type of machinery (lower or higher output, universal machinery, etc.). This also influences evaluation of economic effectiveness of projects – when acquisition costs in a project are high, the probability of positive evaluation of project becomes substantially lower.

Practical application of these findings made use of BIM in order to establish estimated price for construction mentioned in chapters 5.1 and 5.2. Quantity takeoff, which was created with the use of the model, was then utilized to establish costs based on DCE and PAI. The output is presented in Figure 4.



**Figure 4.** Comparison of price estimates for stretch of highway D4 and D1 (source: authors with use of [6, 7]).

The difference between estimated price as stated by DHM and price obtained by matching cost estimate database with BIM model is roughly under 10 %. There are several possible factors that may have caused the difference, such as the interference of expert commission in total price estimate – for one thing due to potential risks, for another to conform some of the prices to specifics of construction zone. However, it is more interesting to compare DCE and PAI estimates. The substantial difference is likely to have originated in lower level of aggregation in units of DCE, which results in a more precise estimate of construction costs.

## 6. Conclusion

As the text of conducted studies obviously states, the issue of estimating construction costs in transport constructions is very broad and interesting from its economic-technical aspect. New solutions, which support precision in calculating expected costs, are fully in accordance with public interest, especially in such large and financially demanding constructions as demonstrated [10]. BIM tools and their proper usage are a potential solution to one of the most topical dilemmas of cost estimates in construction projects.

Analysis of BIM models provided by private subject unfortunately pointed out inadequacy of marketed models for automated evaluation, according to price systems. Models lack measurements of objects and objects themselves are highly aggregated. Case studies of a stretches of D4 and D1



motorways connects BIM model to cost estimates in systems DCE and PAI. Implementing appropriate tools was rather unobjectionable, supportive BIM tools made it possible to establish price estimates of D4 and D1 motorway stretch construction. The estimates were compared to expected price published by Directorate of Highways and Motorways, as created with use of CES database. The difference between any pair of prices was not higher than roughly 10 %.

Fully automated generation of quantity takeoffs with price estimates based on BIM models (from DCE o CES) needs to go through these phases:

- specify requirements for designers (method of proceeding, specification of commissioner's requirements),
- implement price databases used by DHM in a BIM-compatible database,
- software extension to convert generated data into price databases.

For the successful adoption of BIM in cost estimation in transport infrastructure projects, proper supportive environment is necessary. This is especially:

- specification and standardization of requirements for quantity takeoffs for both client and contractor in typical project stages in standardized digital format, according to defined Common Data Environment (CDE) for transport infrastructure projects,
- creation and development of freely accessible manual for methods of quantity takeoffs and estimation using BIM in specified CDE in accord with Czech long-term BIM implementation strategy, Czech legislation and best practice,
- consistent testing and improvement of best practice, preferably government-driven,
- implementation of innovative methods into education (both tertiary and life-long).

Since the use of BIM for quantity takeoffs is highly dependent on market and pricing system, market push (especially from software developers and pricing systems) and pull strategy is very important.

One of the possibilities, which would allow easier implementation of price databases into BIM model structures, would be general revision of estimating costs of construction production in the Czech Republic. It would be suitable to apply foreign ways of classification and estimation of construction costs, along with utilization of best practices in calculation of quantity takeoffs. CES, which is used in the Czech Republic, classifies units according to type of work, regardless of kind of construction. Foreign classifications, on the other hand, sort construction works according to kind of construction. Another subpart of a more complex solution may also be the necessity to recalculate unit prices in classification systems so that the differences between price estimate and winning bid are not so marked.

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