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An automated nD model creation on BIM models

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Abstract: The construction technology (CONTEC) method was originally developed for automated CONTEC planning and project management based on the data in the form of a budget or bill of quantities. This article outlines a new approach in an automated creation of the discrete nD building information modeling (BIM) models by using data from the BIM model and their processing by existing CONTEC method through the CONTEC software. This article outlines the discrete modeling approach on BIM models as one of the applicable approaches for nD modeling. It also defines the methodology of interlinking BIM model data and CONTEC software through the classification of items. The interlink enables automation in the production of discrete nD BIM model data, such as schedule (4D) including work distribution end resource planning, budget (5D)—based on integrated pricing system, but also nD data such as health and safety risks (6D) plans (H&S Risk register), quality plans, and quality assurance checklists (7D) including their monitoring and environmental plans (8D). The methodology of the direct application of the selected classification system, as well as means of data transfer and conditions of data transferability, is described. The method was tested on the case study of an office building project, and acquired data were compared to actual construction time and costs. The case study proves the application of the CONTEC method as a usable method in the BIM model environment, enabling the creation of not only 4D, 5D models but also nD discrete models up to 8D models in the perception of the construction management process. In comparison with the existing BIM classification systems, further development of the method will enable full automated discrete nD model creation in the BIM model environment.

Keywords: automated nD model creation, BIM, nD, xD, 4D, 5D, CONTEC

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1 Introduction

The construction technology (CONTEC) expert system is existing software originally developed to produce automated CONTEC documentation based on data from construction budgets. CONTEC enables quick modeling of the building process, maintenance, or reconstruction of different buildings and structures by using typical network diagrams planned in advance, which are not created by classical network analysis methods but by an original CONTEC network diagram method. The typical network diagrams can be modified based on the spatial conditions of a certain building and the number of construction works and materials. This method can simultaneously create and update quality assurance checklists, environmental plans, and safety and health plans in direct linkage to network diagrams and time schedules as an integral part of the CONTEC design (Jarský 2011).

Utilization of building information modeling (BIM) has been a phenomenon of past years. BIM is a natural development of the computer-aided design, commonly known as CAD systems, developing the idea of three-dimensional parametric designs into the database models.

In this perception, the BIM model is a database system, where the 3D view represents a visual display of data entered in the model database system. Information from the BIM model may be extracted, modified, and inserted back into the database.

The data structure is usually based on the native structure of individual software or rather on the standards of the company managing the design and, on the definition, stated document called BIM execution plan (BEP) (Matějka 2016). This situation implicates a large variety of structures of the models concerning the definition of individual elements, materials, and descriptions of the individual objects.

The aforementioned situation contributed to the development of several coding systems for the BIM models with the goal of standardizing design and project management approaches.

Current software tools provide only partial support for this demanding assignment. For example, linking building elements of a 3D model with the corresponding construction processes, known as 4D BIM, enables visual analysis of construction schedules (Russell et al. 2009).

Models enriched by a certain type of information are commonly noted as so-called nD models, where *n* represents the amount of information used in the model or, rather, the amount of added information into the model itself. In terms of nD modeling, some researchers use nD to describe the different maturity levels of BIM (Khoshnava et al. 2012). Some researchers (Aound et al. 2005) define nD as an extension of BIM.

The basic requirement for using the models in an aforementioned manner is to have mutual data conformity not only in terms of content but also in a formal way. This is actually the main limiting parameter for wider use of a broader spectrum of existing software and hence defines the need for the data structure or element classification to be standardized. Since 2008, limitation in missing interconnectivity between design packages and other software is being questioned, without reaching acceptable results (Schinler and Nelson 2008).

Through a case study, this article aims to propose and test a new approach in discrete nD model creation by utilization of the CONTEC method using the BIM data. This article defines the means of interlinking and repetitive data exchange between BIM and the CONTEC software and thus creates discrete nD models of CONTEC design. The research goal is to develop an automated method of CONTEC design that enhances 4D and 5D BIM models up to the 8D or rather nD CONTEC model. The method shall be applicable to the existing BIM model in a repetitive manner in different stages of the design process, which is demonstrated through a case study included in the article.

2 Literature review

In a BIM model, almost infinite amount of information may enrich a database system, and, in this perspective, new types of models can be developed. In this regard, a basic BIM model would include material, spatial, and other technical properties enabling its utilization as a basis for design and construction works. The information of the properties can be accessed when needed by any stakeholder. This important feature of BIM provides stakeholder access to information and combinations of information (Lieyun et al. 2014).

While defining nD models are the 3D, 4D, and 5D only commonly accepted levels of BIM model, where the 3D model represents the base of development of a BIM. The 4D model utilizes BIM for project time allocation and construction sequence scheduling and simulation and 5D adding the cost aspect (Lieyun et al. 2014). Automation of the process of the scheduling (4D BIM) was addressed in several research projects in previous years (Huhnt 2005; Hartmann et al. 2012; Sigalov and König 2017).

These models can be created either by using adding construction time information to the particular objects or by linking existing separately elaborated schedules to the models or recently using automatized 4D models creation with the use of data from the data-rich 3D BIM models (Sigalov and König 2017; Wang et al. 2020).

The BIM model expanded by further information is often described as nD models, and this consists not only 4D and 5D but also other aspects of construction such as quality, stability (Sacks and Barak 2008), sustainability (Hu and Zhang 2008), and safety (Chantawit et al. 2005), to name a few. A variety of applications are large with a common nominee of utilization and interconnection of the various database data, which allows dynamic and virtual/visual evaluation of the information. However, the model developed beyond 4D and 5D shall rather be noted as an nD model; hence, there is no common agreement on the numbering above 5D (Aound et al. 2005; Lieyun et al. 2014).

The nD model provides a database allowing all stakeholders to retrieve needed information through the same system, which allows them to work cohesively and efficiently during the whole project life cycle (Lieyun et al. 2014).

BIM is (in terms of basic) an integrated 3D model containing data relevant to all participants of the investment process, including investors, designers, contractors, managers, and owners of the objects (Datacomp 2020).

In this respect, the nD model can be part of the integrated BIM model or set of discrete but interconnected models, the idea of working with discrete models or discrete event simulation (DES) was noted, for example, by Lu and Olofsson (2014) or König et al. (2012). In both cases, for this article, the term 3D BIM as a basic integrated model will be used (Figure 1). 3D BIM serves as a keystone or basis for further populating by data of the higher-order models such as 4D, 5D, and nD.

3 Methodology of research

3.1 Integrated modeling approach

Integrated models are being created using populating 3D BIM model by required data, that is, time (4D), cost (5D), and other (nD). The aforementioned data are then added into the model as a property of individual items as, for example, in the case of the time or as an enhanced property based on material, family, type, and so on in case of the cost information.

In most cases, the information related to more than the property of the object is populated, and, for that reason, to automatize this process, coding system for the data linking has to be developed as an integration interface. Data are then populated directly into the model as a property of the item and therefore considered as an integral part of the BIM database.

The apparent advantage of this approach is the creation of a single database containing all necessary data for all intended purposes stated in the BEP (Matějka 2016) or initially determined by model users for intended purposes.

Such an approach creates one single database with all intended data stored in one model and, therefore, enables better simultaneous use of date for a combination of purposes as well ensures up to date state of the data, that is, data are as current as of the model itself. Data organization can be visualized as an expanding layer of 3D BIM model creating subsets of the complete model database (Figure 2).

A disadvantage of this approach is the large amount of data that have to be processed, even though it might not be needed for the intended purpose at the given moment. Because of the high demand for this approach on computing power and data clarity and conformity, this approach is preferably used in small-scale projects where data volume and thus even reaction time of the software using the BIM data on the standard computers are appropriate.

For the higher complexity models, this approach is contra-productive in the current state of software and hardware development not only in the perception of computing power but also due to high demand for data clarity and conformity through the various models. Furthermore, large databases are forcing the user to work with the data.

3.2 Discrete event simulation

The DES utilizes specialized discrete models derived from the 3D BIM, or discrete models or data sets directly linked to the 3D BIM model (Figure 3). The idea of discrete or standalone databases or in our case models is noted, for example, by Wang et al. (2020). The concept of working

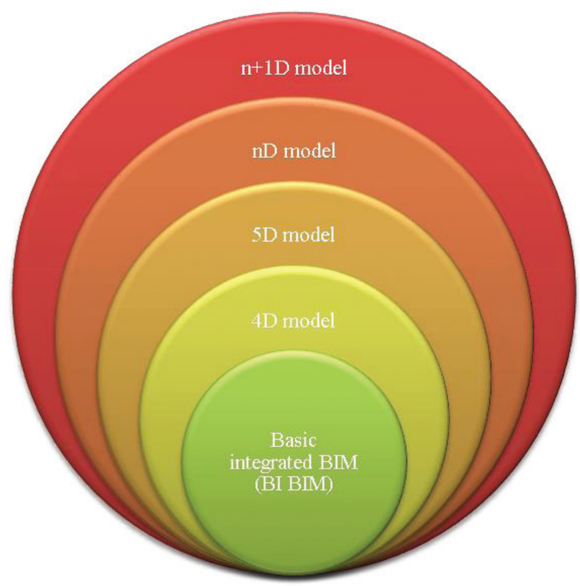

Fig. 2: Integrated modeling approach.

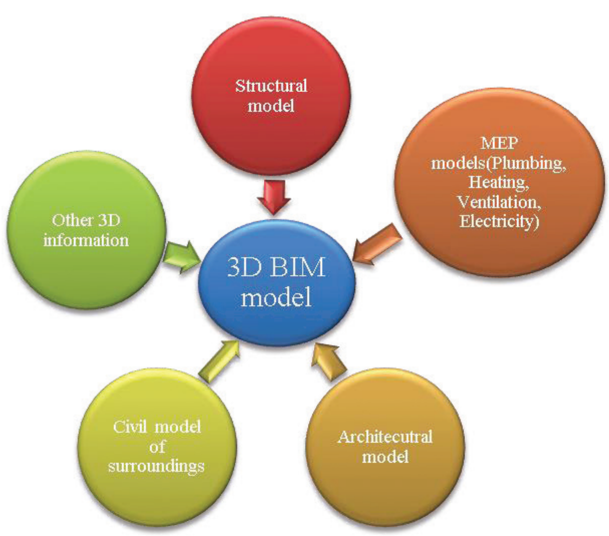

Fig. 1: 3D BIM—basic integrated model.

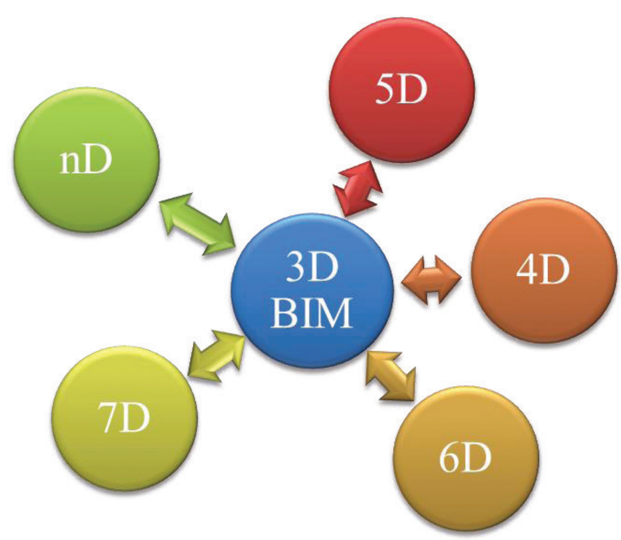

Fig. 3: Discrete model.

with specialized models, such as with structural, light calculation, heat calculation, and so on, is a standard way of working before merging the models into the BIM. When the BIM model is created, not all data is transferred from the specialized discrete model into the BIM thus only defined data (BuildingSmart 2019) transferred into BIM. The discrete modeling concept introduces the idea of specialized discrete models, with the direct interlink to the BIM model enabling repetitive data transfer in between discrete models and BIM aforementioned shall be perceived as nD dimension of 3D BIM. For this article, a dataset can be regarded as a discrete model only when the following conditions are met.

1) Data transfer, that is, individual discrete model (dataset), can be updated based on the BIM data repetitively.
2) Databases of a BIM model and discrete nD model are directly linked to the model items or data, that is, when relevant inputs are changed in the BIM model, discrete model changes automatically after data update.
3) The discrete model contains data developed based on the 3D BIM model (e.g., cost, time, thermal calculation, etc.).

Discrete modeling advantages are mostly derived from the reduced volume of data and the fact that users may use only the data that are necessary for the intended purpose of the sovereign model. Furthermore, data may be sorted and adjusted to the needs of data users. This approach enables to work with a high volume of data and very complex models.

The discrete modeling approach is necessary when working with large-scale models and thus large volumes of data.

In a discrete modeling approach, is the way of linking the models or datasets a key aspect of the correctness and usability of the discrete models, together with the possibility of updates of information across all discrete models?

Currently, apart from the split 3D BIM models, model linking is, in most cases, indirectly achieved by exporting necessary datasets from the 3D BIM and developing or populating these data while working on the specialized model, and this approach is used, for example, in the structural design or thermal calculations, where the results of the discrete modeling and calculation are then in the necessary volume transferred back to the 3D BIM model (Autodesk 2019). These models cannot be perceived as true nD models due to the missing direct linking and automated update possibilities.

Another approach in discrete modeling may be the direct interlinking between discrete models and 3D BIM models, which can be performed manually or semi-manually by linking the necessary data of discrete model to the items or data in the BIM, or in some cases, data link may be created automatically by existing coding systems (BuildingSmart 2019). In this case, data in the discrete model can be automatically updated when 3D BIM is modified or changed.

Automated linking and updates are currently used especially in the case of 4D and 5D models, where existing software systems (OCCS 2017) are designed for this purpose.

However, this article intends to demonstrate the possibilities of automatized nD model development by interconnecting the existing non-BIM software, in this case CONTEC, with the various BIM models through the coding interface (Jarský 1994). Through the CONTEC discrete output data of nD BIM model, such as schedule/network diagram (4D), cost and financial plan/cash flow (5D), as well as data of nD models such as quality assurance and testing plan (6D), environmental plan (7D) health and safety register and risks plan (8D), as well as other data such as resource or various other analyses are then created.

A combination of the proven approaches with the new trends in construction design and construction management in this case represented by BIM may open the new possibilities for increasing productivity in the construction process not only in the pre-construction phase but also in the execution of the works. This process enables the transfer of the resources, increases the attention of the project managers from the process-oriented tasks, such as manual planning, costing, creating base health and safety registers, and setting up quality assurance checklists to the improvement-oriented tasks such as optimization and maintenance of all aforementioned tasks.

Based on the above-described modeling options of integrated and discrete modeling and with the aim of the research to create nD models using the CONTEC method. With CONTEC and BIM models, the discrete modeling method was selected as best suited for use.

CONTEC software allows the input and retrieval of data and specifications arising from various constructional and technological conditions of the construction process, predominantly from bill of quantities produced by a designer or by consultants of the developer, from the budget or eventually from calculations or invoices in the ideal state in an automatized manner (Jarský 1994).

The whole methodology of automated model creation in the CONTEC expert system is described by Jarsky (2000) and Jarský (2010), which is why this article does not elaborate in detail on the software itself but rather on means of directly interlinking CONTEC expert system as software to the BIM model as a database to create nD models.

For this article, the Revit software by Autodesk was used in case study, but any BIM software enabling data transfer through.csv and.xlsx may be used with the method.

4 Developing nD models through CONTEC method

As stated above in this article, the BIM model is, in principle, a database of information that can be utilized or interlinked with other databases or software or to serve as a base of information used for various tasks.

CONTEC method was developed for automated technological design based on construction budgets data (Jarský 1994) since the budget is essentially a database of information as well as BIM model, the method was selected as applicable with BIM.

To create nD models through the CONTEC expert system, data from BIM have to be interlinked and transferred or to the CONTEC to be processed. Processed data can be either handled as discrete models nD or through reverse upload to the BIM model may create integrated nD models. This process shall be performed repetitively on demand of the users, especially in the cases when model data have changed. A typical application of this process would be an evaluation of the project from the perspective of the investment cost and maintenance cost (Jarský 2011), health and safety (Jarský and Gacho 2014), quality, environment, and so on in various stages of development.

To achieve an aforementioned goal, either a common classification interface must be used or coding interlink must be created. As stated in the introduction, classification systems are undergoing fast development are very often country-specific or even company-specific. This article addresses two approaches in which CONTEC's root coding system is used in the 3D BIM model in the first approach and in the second approach in which general 3D BIM coding is used, and interlink between CONTEC and 3D BIM is defined and set for the automatized data transfer.

5 Selection of applied classification system

CONTEC classification system is derived from the Czech national standard called classification of building constructions and works (TSKP—Třídník stavebních konstrukcí a prací).

TSKP is based on price systems delivered in public tender proposals by engineering companies. These data are regularly maintained by the state that hires a private company to do so. Using the software tool with available functionalities and workflows, it is almost impossible to model the information model so that it can be represented in the TSKP structure. The price systems also use types of items that have a direct connection with the construction/activity, but their modeling in the information model would be very slow, impractical, and would require designers to have cost estimation principles knowledge. Types are, for example, surcharges for work at heights, dusty environment, and so on. That is why in many countries these classic classification systems are replaced by new ones, such as Uniclass predominantly used in the UK, OmniClass which originated in the USA, CoClass—Swedish classification system (Vitásek and Žák 2018) or eventually local or company-specific classification systems.

CONTEC classification system was selected due to its conformity with the TSKP classification system which is standard to the Czech construction environment, where case study project was executed and because for other classification system such as Uniclass (NBS 2015) or Omniclass (OCCS 2017) or local BIM-based SNIM (Vitásek and Žák 2018) would require creation of transformation database, and will be subject of further research.

Selection of the classification system for the purpose of the data interlink with the CONTEC has to be executed based 3D BIM properties (Figure 4).

CONTEC classification system was developed based on the following principles based on TSKP which divides construction and work for construction production into nine groups of building parts based on construction processes, work gangs, and technological stages (Vrána 1999):

1. Earthworks
2. Special founding, foundations, and hardening of rocks
3. Vertical and complete construction
4. Horizontal construction
5. Other communications
6. Finishing of surfaces, floors, and assembly of openings
7. Construction and work of secondary building production
8. Pipelines
9. Other constructions and work, cutting, scaffolding, and material transfer.

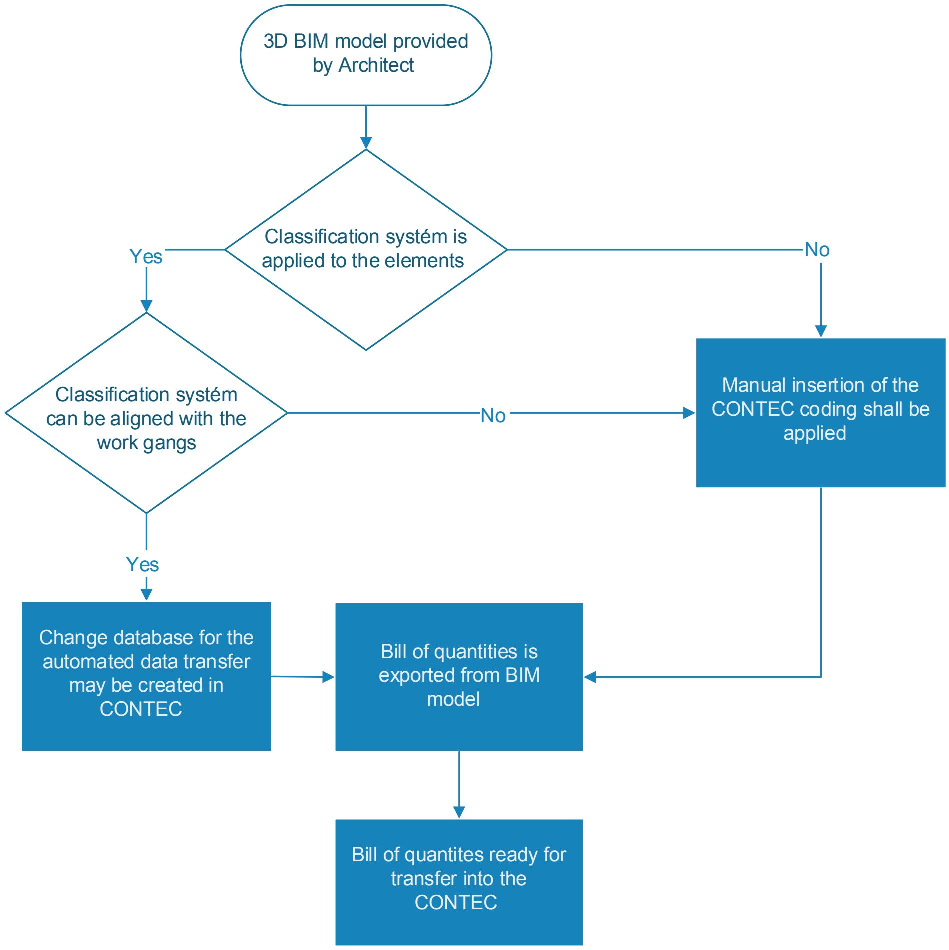

Fig. 4: Classification system decision process.

The database activities are numbered with four-digit indexes. The designation of the building parts group acts as the first character of the activity number. The second character describes the specific building part in the TSKP. So, for example:

3 Vertical and complete construction
31 Wall supports and loose
32 Wall and retaining walls

The third character distinguishes the type of structure, the subgroup of works, or the craft. However, for technological reasons, it is only monitored for a group of building parts 7, 91–95, and case 979. For the other groups, the designation of activity is zero in the third place. Therefore, the first three places of the label may look like:

3 Vertical and complete construction
31 Wall supports and loose
310 Wall support and free walls

The fourth character refers to the technological stage (TE). In theory, each group of the first three characters can bind to any TE. In practice, however, these links are limited, and the joining of groups of the first three characters with technological phases is, if possible, logically chosen in the activity figures.

Following are technological stages (TEs) of the buildings (Jarský 2015):

0. Earthworks + demolitions
1. Foundations
2. Underground structure
3. Above ground structure
4. Roof
5. Execution of partition walls and mechanical, electrical, and plumbing (MEP) installations
6. Execution of plasters and base layers of floors
7. Execution of floors, surfaces, finalization of MEP
8. Completion of MEP and interior surfaces
9. External works
10. Commissioning and quality assurance

A technological stage is a group of structures and works defined concerning time and area of implementation. According to TSKP, classification of activities allows to use the division of the building structures and works according to the constructional point of view regardless of the construction sector and time or local factor. The numbering of the database activities is chosen to combine these two principles (Jarský 1994).

6 Data interchange between BIM and CONTEC

To be able to transfer necessary data from BIM into the CONTEC, a database interlink has to be created. In general, two approaches are applicable based on the quality of the model and level of the development, and it is a direct application of the classification coding into the BIM or automated interlink to the existing classification system, which was applied to the model. For this article, the direct application of the classification coding into the model will be described. Direct code application is best suited in the following cases:

(1) BIM model does not include any classification system
(2) Models are in the low level of development or classification system in the model shows a high level of unconformity
(3) The applied classification system does not enable to differentiate structures or works, which shall be executed in different technological stages.

Furthermore, for the success, full data transfer in between BIM and CONTEC in both cases of automated and direct coding application with respect of all above mentioned following criteria must be met:

(1) Every item must have a classification code, same items must have the same code, different items must have a different classification code
(2) Item carries quantity information such as volume, area, and so on.
(3) Data conformity of a model is kept (the same items have the same classification codes and properties).
(4) Item has a description in item name, class or family to enable verification for data conformity of classification and description.
(5) Items in the model are created with respect to the means of technological modeling, that is, execution of the building.

Works or items missing in the model must be known to the person performing the data transfer in the cases when the aforementioned criteria are not met, and, in some cases, data transfer would be either difficult or impossible.

7 Direct application of the CONTEC classification coding into the BIM model

Typically, the designer who creates a BIM model does not have expertise in technological modeling hence is not developing the model concerning the construction processes. In this case, 3D BIM has to be modified for technological needs or classification has to be applied by a trained specialist with regard to the technological processes.

This approach shall be applied especially in the cases where 3D BIM does not carry any classification system which could be used for the automated transfer, or classification coding cannot be linked to the work gangs or concrete technological stages. Typically, an example would be when underground structures carry the same classification of coding as the superstructure construction processes or when the 3D BIM model is not complete, that is, some submodels are missing (typically MEP in the early stages of model development).

During the further development of the model, coding can be added for the newly designed items or inherited (Veng 2019) for the newly designed, yet existing items. Furthermore, libraries (Kvirenc 2017) may be created derived from existing projects for further utilization by design or development companies.

For the purpose, four-digit CONTEC code was applied in bellow case study into the model using the creation of shared parameters (Kvirenc 2017). In the early phase of the zoning permit and then regularly updated during the design process. The CONTEC coding system is based on the database of activities and work gangs on-site in concrete technological stages.

Therefore, classification coding was applied concerning the future utilization for the technological modeling based on the assumed technological work distribution in technological stages as well as with the high enough level of aggregation to suit the BIM model and to overcome the differences in between classification system and BIM model.

The classification system, that is, individual classification 4-digit CONTEC codes, was applied to individual

BIM items or, if possible, to group of items (Veng 2019). In special cases, codes were applied to the individual items or group of items where, for example, position or type of the item was defining the technological process. A representative example would be hydro-insulation of substructure or hydro-insulation of a roof or in case substructure and above-ground structure of concrete, where positions of the item in the project define the technological stage.

During the process of the code application, various properties may be used based on the LOD (Building 2019) to filter and group various items based on their specific presence in the model or material specification.

Coding was performed by two basic methods, either by Creation of shared parameters (Kvirenc 2017) or by the export of the bill of quantities into the.csv file where necessary codes were inserted and by this means implemented back into the BIM model in this case in the Revit system (Figure 5).

Manual application of classification was performed through excel sheet and by reverse upload applied to the 3D BIM through design software, although this did not prove effective because the design models are not yet ready for CONTEC modeling , and their division into the logical complexes does not follow technological principles of CONTEC modeling or rather does not include sufficient descriptions enabling proper interlink with activities. For example, they do not differentiate bearing structures and partition walls or do not differentiate substructure or superstructure constructions.

Direct application of the classification into design software proved to be more effective, due to the possibility of visual verification of the classified elements, as well as to the possibility to manually verify data conformity and quality directly in the model. Furthermore, some structures, like shafts, or substructure exterior walls had to be divided and assigned to the respective floor to enable proper CONTEC modeling.

Manual coding procedure proved that the BIM models are designed in such a way where they do not follow technological processes of implementation of the building and automated processing of the data to ensure that the designer sets up a model properly and that this approach is also suitable for projects where the BIM models are not developed concerning the CONTEC design principles.

Further development of the utilization of the TSKP/CONTEC coding in the BIM design process, is that design libraries, derived from the project where the aforementioned coding was applied may be used as a base for the

Type	Code	Abrev	Work	Volume	Unit
900x350_hl2700x2200x100 2	3302	SLOU2	PILLARS OF UNDERGROUND	1,76	m3
900x350_hl2700x2200x100 2	3302	SLOU2	PILLARS OF UNDERGROUND	1,55	m3
900x350_hl2700x2200x100 2	3302	SLOU2	PILLARS OF UNDERGROUND	1,55	m3
900x350_hl2700x2200x100 2	3302	SLOU2	PILLARS OF UNDERGROUND	1,55	m3
900x350_hl2700x2200x100 2	3302	SLOU2	PILLARS OF UNDERGROUND	1,55	m3
900x350_hl2700x2200x100 2	3302	SLOU2	PILLARS OF UNDERGROUND	1,55	m3
900x350_hl2700x2200x100 2	3302	SLOU2	PILLARS OF UNDERGROUND	1,55	m3
900x350_hl2700x2200x100 2	3302	SLOU2	PILLARS OF UNDERGROUND	1,55	m3
Betonový sloup D 500mm	3303	SLOU3	COLUMNS AND PILLARS	0,8	m3
Betonový sloup D 500mm	3303	SLOU3	COLUMNS AND PILLARS	0,73	m3
Betonový sloup D 500mm	3303	SLOU3	COLUMNS AND PILLARS	0,73	m3
Betonový sloup D 500mm	3303	SLOU3	COLUMNS AND PILLARS	0,71	m3
Betonový sloup D 500mm	3303	SLOU3	COLUMNS AND PILLARS	0,64	m3
Betonový sloup D 500mm	3303	SLOU3	COLUMNS AND PILLARS	0,62	m3
Betonový sloup D 500mm	3303	SLOU3	COLUMNS AND PILLARS	0,64	m3
Betonový sloup D 500mm	3303	SLOU3	COLUMNS AND PILLARS	0,64	m3
Betonový sloup D 500mm	3303	SLOU3	COLUMNS AND PILLARS	0,64	m3
Betonový sloup D 500mm	3303	SLOU3	COLUMNS AND PILLARS	0,64	m3
Betonový sloup D 500mm	3303	SLOU3	COLUMNS AND PILLARS	0,64	m3
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Betonový sloup D 500mm	3303	SLOU3	COLUMNS AND PILLARS	0,64	m3
Betonový sloup D 500mm	3303	SLOU3	COLUMNS AND PILLARS	0,64	m3
Betonový sloup D 500mm	3303	SLOU3	COLUMNS AND PILLARS	0,64	m3
Betonový sloup D 500mm	3303	SLOU3	COLUMNS AND PILLARS	0,64	m3

Fig. 5: Sample of manual classification coding.

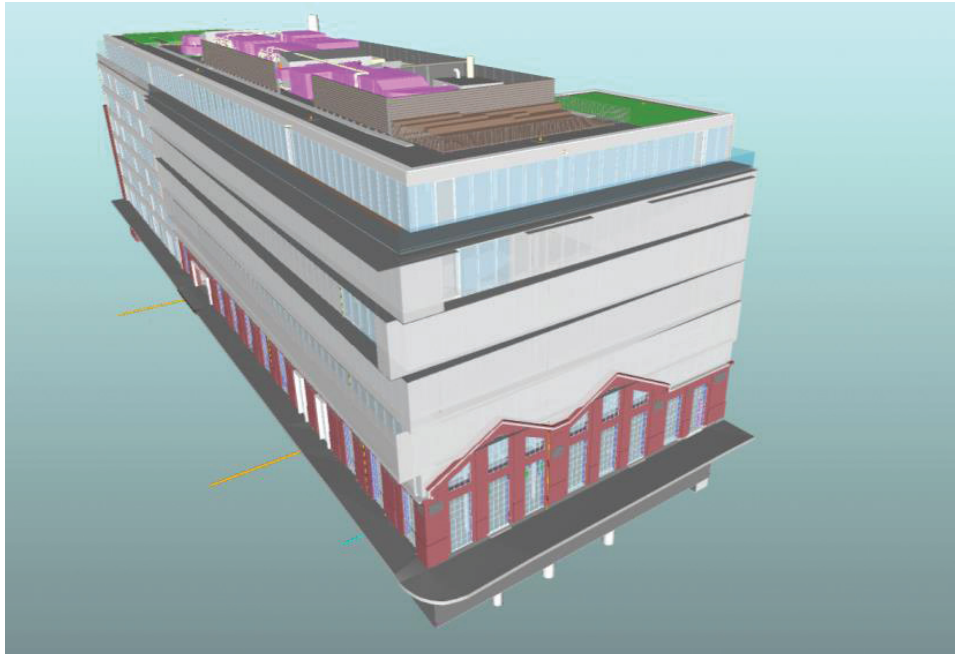

Fig. 6: Office building FIVE BIM model.

further design if desired by the investor. This may lead to the automated transfer of the date from a 3D BIM model to the CONTEC and in the case that technological principles in design works were met, also to the automated creation of the nD models.

8 Case study manual classification of the existing model

Manual application of classification system was used on the project of the office building called FIVE and implemented by Skanska in Prague. Project FIVE was one of the first implementations of the BIM design in the Czech Republic, and for this reason, no classification system was applied to the BIM model in the first place. Furthermore, due to the complexity of the building and the quality of the information included especially in the heating, ventilation, air-conditioning, and electrical models, the classification system was applied only to the structural and architectural model. Securing of the construction pit, excavation works, restoration works, demolitions and underpinning of the surrounding buildings were not modeled in the BIM, and for this reason, it was not a subject of the data transfer between BIM and CONTEC.

Data created by CONTEC were compared to the actual construction times (site log book), worker presence (site log book), project cost (invoices and budget), and so on by one of the authors, who was the project manager responsible for the execution of the project and therefore had access to the internal company project data.

Project FIVE (Figure 6) is an office building with two underground floors and seven above-ground floors with the 20,000 m^2 of the gross floor area and as such represents the typical size of the office building project executed in Prague.

Project FIVE had a complete 3D BIM model consisting of structural, architectural, heating, cooling, ventilation, piling, 3D scan of historical walls, and surrounding buildings, which is visible on the 3D section of the building (Figure 7).

A classification system was applied manually in the software Revit by the method of shared parameters briefly described in the aforementioned text.

Report tables for the transfer bill of quantities were set up, and reports were created in the form of.xlsx files (Figure 5).

Coding was performed only on structures and architectural parts, and none of the models of the MEP was designed at the time of the test. CONTEC enables CONTEC modeling even with incomplete data based on the type of the structure and volume of the structure.

Manual coding of the case study project was executed by a single person in the early stage of the project design (building permit design) and was further inherited to the execution and even as build design.

After the application of the CONTEC classification, data were transferred through a bill of quantities in the

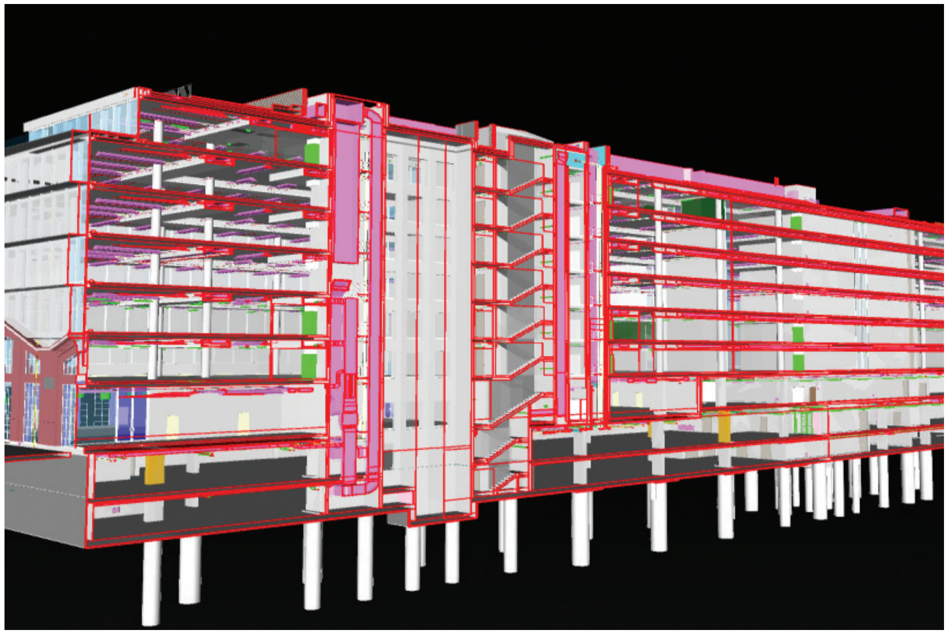

Fig. 7: 3D section of the building FIVE.

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15.8.19

Critical activities are written in red, delayed in blue.

Index Stage Item	Activity name Cost calcul.item's name	M. u. Supplier M. u.	Quantity [M. u.] Quantity	Price [TKč] Price	Time stand. TS tension % Coeff.	Lab.cons. standard Mh Lab.cons.	Lab.cons. actual Wh Mh	Workers Shift/day	Duration Float	Start early	Finish early
	01 Adm.building										
301	EXCAVATIONS	M3	10074	2135.74	0.150	1511	1511	5	6	3.7.17	12.8.17
0	01 Adm.building	/			100			1	0		
501	SHEETING OF EXCAVATIONS	M2	1047	253.30	0.540	565	565	2	6	10.7.17	19.8.17
0	01 Adm.building	/			100			1	0		
601	TRASPORT OF SOIL	M3	10074	1591.73	0.130	1310	1310	4	7	3.7.17	19.8.17
0	01 Adm.building	/			100			1	5		
701	FILLINGS AND HEAPS	M3	7506	2131.63	0.010	75	289	1	6	3.7.17	12.8.17
0	01 Adm.building	/			26			1	6		
802	FOUNDATIONS BEDDING	M3	353	345.65	1.040	367	367	2	4	7.8.17	2.9.17
0	01 Adm.building	/			100			1	3		
1352	PILES DRILLS	M	447	2105.84	1.140	509	509	6	2	21.8.17	2.9.17
1	01 Adm.building	+			100			1	0		
1402	PILES	M	447	2403.22	2.060	920	920	6	3	28.8.17	16.9.17
1	01 Adm.building				100			1	0		
2201	Pilota 630	M	5.87	0.00	1.000	0.00	0.00				
2201	Pilota 630	M	7.42	0.00	1.000	0.00	0.00				
2201	Pilota 630	M	7.40	0.00	1.000	0.00	0.00				
2201	Pilota 630	M	7.40	0.00	1.000	0.00	0.00				
2201	Pilota 630	M	7.40	0.00	1.000	0.00	0.00				
2201	Pilota 900	M	7.42	0.00	1.000	0.00	0.00				
2201	Pilota 900	M	7.42	0.00	1.000	0.00	0.00				

Fig. 8: Technological analysis.

form of an excel sheet directly exported from REVIT (Figure 5) into the CONTEC software, through the inbuilt transfer protocol for the bill of quantities. Through the classification codes were the quantities linked to the work gangs, and the following technological design documentation was created.

The basic document of the CONTEC model is the technological analysis (Figure 8) developed from the combination of the information from the BIM model and data preselected technological model based on the type of the building, where items transformed from the exported bill of quantities are visible, for example, at the case of process

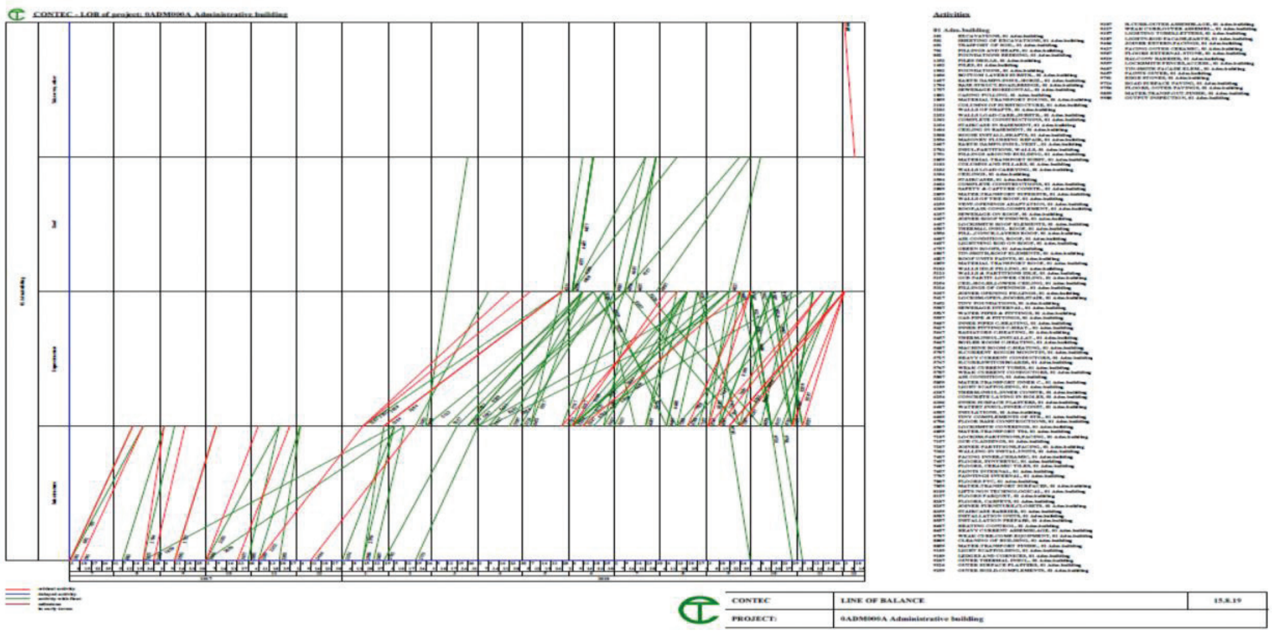

Fig. 9: Line of balance of project FIVE.

nr. 1402—items written in small letters, and, on the contrary, processes written in CAPITAL letters without breakdown were calculated from the type network diagram.

The schedule and line of balance (Figure 9) were created based on the data, representing 4D of the original BIM model. Based on the 4D model construction, duration was 18 months, in comparison with the actual construction time of the project representing 19,5 months.

The biggest differences between modeled execution times and as-build construction times were in the special foundation—underpinning of surrounding buildings. As well as in the restoration of a historical wall, which was visually present in the BIM model but could not be exported in the bill of quantities as it was not newly implemented in the first place, but restored according to the requirements of heritage office.

This feature was not included in the BIM model; therefore, it could not be transferred into the CONTEC. Naturally, this discrepancy may be easily manually adjusted, yet it was kept as automatically calculated to demonstrate the main restriction which has to considered when creating automated schedules, that is, that information which is not included in the BIM model has to be either calculated or manually entered. Furthermore, weather-dependent tasks, like the execution of roofs, has to be considered when the automated creation of the 4D model is performed.

5D model was created by the automated pricing of the model, based on the integral CONTEC database creating a 5D model (financial data) including its distribution in the time (Figure 10). Figure 10 provides important information especially for the investors when securing the financing of the project.

Apart from the financial data, other resources, like human resources (Figure 11), was created in form of graph of a number of people in time. The number of workers calculated by the CONTEC method was compared to the actual presence of workers on-site, especially in the peak phase. Where the number of 106 workers was calculated by CONTEC in comparison with the actual presence of a maximum of 115 (as per site log book), is an accurate result in the perception of dimensioning of site facility.

This feature enables proper dimensioning and planning of site facilities during the permitting process as well as control the cost of the site facility (site cabins, toilets, showers meeting rooms, changing rooms, etc.).

Models of the higher-order nD were then represented by health and safety plan and plan of quality assurance.

9 Results and further research

Manual application of the classification system into the existing model is a time-consuming and tedious work, yet proves to be an effective solution in the cases when no classification system was applied into the model, or data inconsistency is high. To properly set up export tables, data transformation from the BIM model into the CONTEC had to be executed with several iterations. The process of data transfer was demonstrated on the REVIT software,

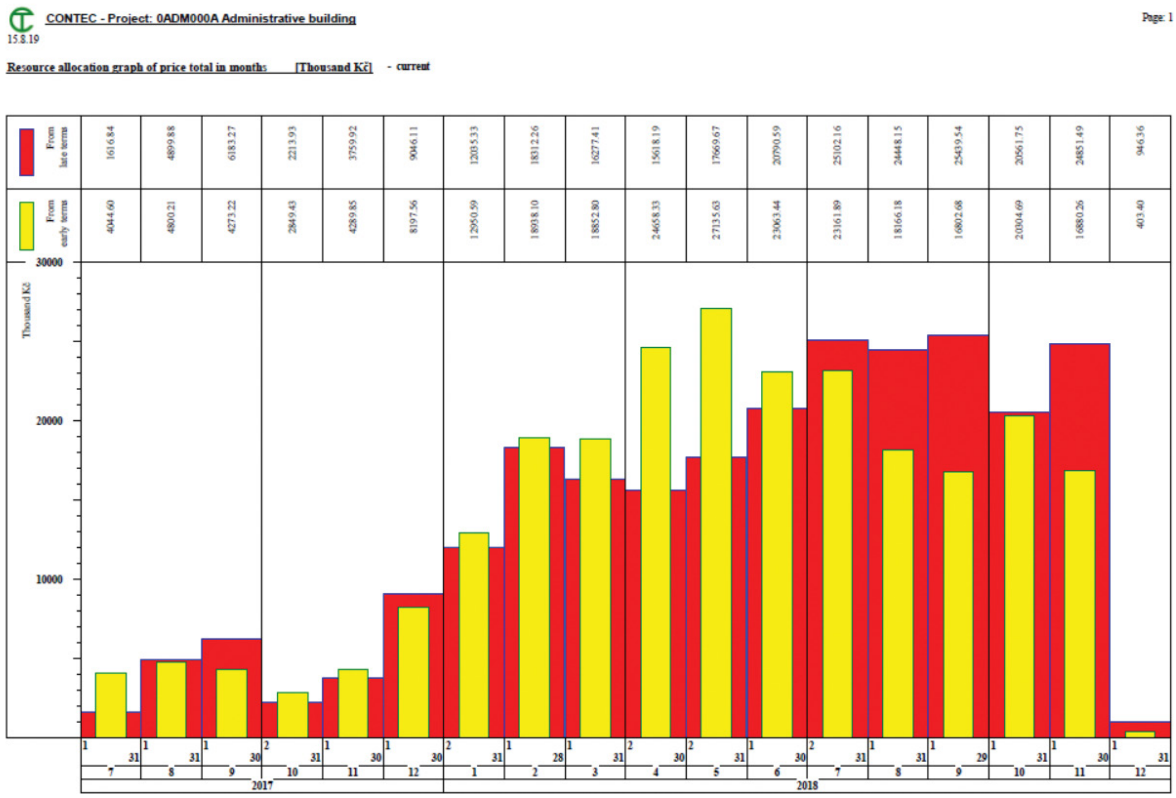

Fig. 10: Allocation of financial resources in time.

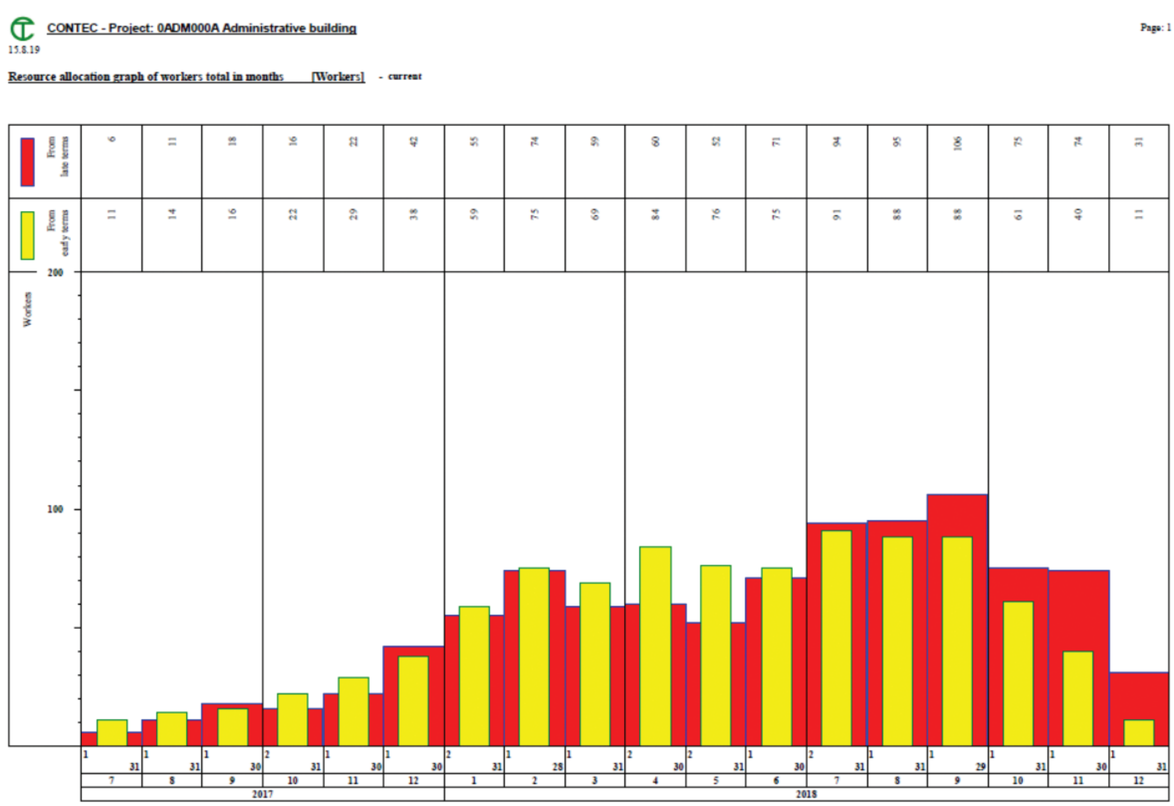

Fig. 11: Resource graph—people.

yet the proposed method applies to any design software that enables import and export of data through the.csv or.xlsx tables.

A case study proved that after successful set up of the export measure units were aligned, and because CONTEC classification was used, the database alignment was done automatically through a transfer of the bill of quantities process.

The creation of the discrete nD models from the exported BIM data was then processed through CONTEC modeling in CONTEC with acceptable results, despite the fact that the BIM model was not fully coded, that is, the technological part of the model was not transformed into the CONTEC.

One of the most important CONTEC features proved to be a possibility of CONTEC modeling using incomplete data from the model (aligned to the respective part of the pre-set technological model). This feature opens great opportunities for the evaluation of the projects and CONTEC planning and assessment in very early stages of the design process.

Applied codes from the model as well as export tables are reusable for the future project provided that developed BIM families and tables are exported as a BIM library. This feature enables the development and implementation of classification in small companies or developing markets.

Despite demanding application of the classification to the model, the method proved effective because the completed data from the model may be extracted repetitively during the design process. The proposed method also applies to existing classification systems, but it is especially useful in countries where the development of BIM is in the early stages. The case study shows results comparable to the actual execution data of the selected project.

Automated nD creation through the CONTEC is applicable to the BIM models with results comparable to the real execution times and costs. The method proved to be applicable to BIM models in various stages of model development, starting in building permit up to the execution stage. The CONTEC method enables the automated elaboration of not only 4D and 5D models but also nD models of technological modeling such as 6D resource plan, 7D health, and safety risk register, 8D quality and assurance plan, or 9D environmental plan.

Automation in technological modeling has a great potential in saving resources of project teams as well as enables repetitive verification of the feasibility of design concepts. Early evaluation of design concepts and constructability of project in early phases of design may be source of considerable savings in execution process and as such as worth of further investigation.

Further development of the method is the development of automated linking to the existing classification systems by creating a classification interface between the CONTEC classification and generic classification system, enabling full automation of the process.

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