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On BIM based automatized nD modelling for construction management

DOCTORAL THESIS

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DECLARATION

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Title of the doctoral thesis:

On BIM based automatized nD modelling for construction management

I hereby declare that this doctoral thesis is my own work and effort written under the guidance of the tutor Prof. Ing. Čeněk Jarský, DrSc., FEng.

All sources and other materials used have been quoted in the list of references.

In Prague on 24.8.2019

Signature

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Abstract

Thesis outlines new approach in automated creation of the discrete nD BIM models by interlinking and utilization of existing CONTEC (Construction Technology) method, originally designed for automated construction technology planning and project management based on data in the form of budget or bill of quantities. CONTEC enables automation in production of nD model data such as schedule(4D) including work distribution end resource planning, budget(5D) – based on attached pricing system, but also nD data such, as health and safety risks plans (H&S Risk register), quality plans and quality assurance checklists including their monitoring and Environmental plans. Thesis includes practical example of interlinking existing BIM model without classification system to the CONTEC system and automated creation of above mentioned nD models. Proposed method is applicable also to existing classification systems but is especially useful in countries where development of BIM is in early stages.

Abstract in Czech

Práce nastiňuje nový přístup k automatizovanému vytváření diskrétních modelů nD BIM prostřednictvím propojení a využití stávající metody CONTEC (stavební technologie), původně navržené pro automatizované plánování stavebních technologií a řízení projektů na základě údajů v podobě rozpočtu nebo rozpisu množství. CONTEC umožňuje automatizaci výroby dat modelu nD, jako je například plán (4D) včetně plánování zdrojů distribuce práce, rozpočet (5D) – založený na připojeném cenovém systému, ale také údaje nD, jako jsou plány na ochranu zdraví a bezpečnosti (plán rizik BOZP), KZP a kontrolních plánů BOZP a environmentálních plánů. Práce zahrnuje praktický příklad propojení stávajícího modelu BIM bez klasifikačního systému do systému CONTEC a automatizovaného vytváření výše zmíněných modelů protokolu nD. Navrhovaná metoda je použitelná i pro stávající klasifikační systémy, ale je užitečná zejména v zemích, kde je vývoj BIM v raných fázích.

Key words

Automated nD model creation, BIM, nD, xD, 4D, 5D, CONTEC

Chapter 1 Introduction

Utilization of the Building Information Modelling commonly known under abbreviation BIM became phenomena of past ten 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. These models are then enabling use of wide variety of application.

Common nominee of above mentioned applications is utilization of 3D parametric models commonly known as BIM.

BIM is covering wide range of applications used during the whole lifecycle of the building. List of the software is ranging from design software, construction management software to facility management software where date from the BIM models may be utilized to visualize or to populate existing databases.

Building Information Modelling (BIM) is defined as “a digital representation of the physical and functional characteristics of a facility”. [1]A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle. Database is defined as existing from earliest conception to demolition [2].

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

A BIM model is different from traditional 3D CAD models in which 3D CAD only describes a facility with independent 3D views, such as plans, sections and elevations. If one of those views is modified, the others must be updated accordingly. Further, data in 3D CAD drawings are only graphical entities, such as lines, arcs and circles. On the contrary, a BIM integrates semantically rich information related to the facility, including all geometric and functional properties during the whole life cycle in a collection of “smart objects” [3]

The main differences between the standard 2D drawings and 3D BIM models are in the database organisation of the information where visual interpretation of the database is just one of the information included in the BIM model database. Data itself are related to individual components of the model such as wall, pillar etc. Every component bares unique identification code called Global Unique Identifier (GUID), information of special and dimensional relationships, information of type and material as well as any other information inserted by user into the model. Information and specification can be inherited from the parental classes. For that purpose, are models organized into families. Information organized in such a manner are than usable in the wide array of applications capable to harvest and utilize data from the BIM models.

Data structure of the information included in the BIM models in the Czech Republic is currently neither defined in the technical nor in the legislation standards. Due to that above stated fact the approach to definition of the data structure is variable and individual to every project and from that perspective creates the greatest obstacle in finding unified approach to data extraction and usage. The data structure is therefore usually based on the native data structure of individual software or rather on the standards of the company managing the design and, on the definition, stated in the BIM execution plan (BEP) [4]. This situation implicates large variety of structures of the models with respect to the definition of individual elements, materials and descriptions of the individual objects. Yet another issue is definition of naming and coding standards which varies in between the projects, or even individual designers on one project, creating issue with data conformity not only between different projects but within on project i.e. one BIM model.

Despite the fact that coding systems in use for the BIM models such as Omniclass [5] or Uniclass [6] are often natively implemented in the design software, until today, neither Omniclass nor Uniclass evolved into the recognized classification standards fulfilling the current needs of the construction industry in the Czech Republic and neither designers nor investors are willing to accept these classification systems as a market standard.

Above-mentioned situation resulted into the development of several coding systems for the BIM models with the target to standardize design and project management approaches. This sole issue of undefined data structure of the models is one of the main obstacles of the development of the use of BIM in the Czech Republic. Based on this situation, all solutions which are focusing on usage of the BIM data under current conditions must be versatile to any classification system i.e. usable with any systematic classification system.

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 Building Information Modelling (BIM), enables a visual analysis of construction schedules [7].

Automation of the process of the scheduling on the base of the BIM were addressed in several research projects in previous years [8] [9] [10].

The basic requirement enabling the models to be utilised in above mentioned manner is to have mutual data conformity not only in content but also in formal way. This is currently the main limiting parameter for wider use of broader spectrum of existing software and in this way is defining necessity of standardization the data structure or element classification. Limitation in missing interconnectivity between design packages and others software is being questioned [11] since as early as 2008 without reaching acceptable results.

In this moment in the Czech Republic there is no BIM data structure defined by the means of legislation or technical norms. Current technical standards are applicable only to the paper print-outs from the models. Information value of the models is much higher in compare to traditional CAD data or printed documentation and their non-use represents considerable data loss and especially of the data already entered into the model, causing high ineffectiveness of the process. Correctly defined data structure for the BIM models can therefore impact the effectiveness of the construction process. By defining either element coding system or means of connecting existing coding systems into the existing software solutions would be a major accelerator of BIM development and implementation.

In the perception of the European norm and legislation, inspiration can be drawn from the Nordic countries, where there are national standards defined by governmental institutions, and also in Great Britain where BIM requirements were defined by *PAS 1192-2:2013 Specification for information management for the capital/delivery phase of construction projects using building information modelling*, which is one part of the initiatives started to increase construction industry productivity.

The goal of this thesis, with respect to the current market condition and unclear development of the situation, is to describe principles of the elaborated applicable method of extraction and utilization of the data from the BIM models to develop so called BIM models of higher order commonly called nD or xD models. This method shall be applicable for various classification systems currently in use or developed in the Czech Republic, but also it shall be applicable to any general classification system currently in use worldwide. Existing coding systems will be evaluated and tested in the case studies. Interface will be created between existing software CONTEC [12] and BIM models utilizing various coding systems and models of higher orders such as 4D, 5D and nD will be created.

By this means information which is included in BIM models can be enhanced not only by information of technological assessment, execution time, construction cost, but also of health and safety issues as well as environmental and quality information.

Chapter 2 Current state of knowledge

In the past years various research papers were dealing with the use of BIM models for purpose of automatized creation of 4D or even 5D models. [7] [8]

Providing that a BIM model is a database, almost infinite number of information may be added to enrich this database system, and, in this perspective, new types of models may be developed. A basic BIM models would in this regard include material, spatial and other technical properties enabling its utilization as a basis for design and construction works.

In such a model, each component shall be regarded as a “smart object” with all associated parameters stored in it can be defined. The information of the properties can be accessed when needed by any stakeholder. This important feature of BIM allows stakeholder access to information and combinations of information. [12]

Models enriched by certain type of information are commonly noted as a so called nD models, where n represents level of information included in the model or rather level of added information into the model itself.

In terms of nD modelling, some researchers use nD to describe the different maturity levels of BIM [13]. Some researchers define nD as an extension of BIM [14].

In this respect the only widely accepted levels of BIM model are 4D model and 5D model, where 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 [12]. These models can be created either by means adding construction time information to the particular objects or by linking existing separately elaborated schedules to the models, or recently by means of automatized 4D models creation with use of data from the data rich 3D BIM models [8].

Furthermore, model can be expanded by adding cost information to the 4D models, for this approach the term 5D is being used by several authors [5] since as early as 2008. Unlike in the case of 4D model discrete model contains the cost information without the time information is not being widely used.

The BIM model expanded by further information are often described as nD models, this consist not only 4D and 5D but other aspects of construction as quality, stability [15], sustainability [16], and safety [17] to name a few. Variety of applications is large with common nominee of utilisation and interconnection of the various database data, which allows dynamic and virtual/visual evaluation of the information. However model developed beyond 4D and 5D shall rather be noted as a nD models hence there is no common agreement on the numbering above 5D [14] [12].

This 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 [12]. Meaning all models are interconnected and therefore possible to update on demand or automatically when core information database (in this case BIM model) is changed.

The nD model can be in this respect part of the integrated BIM model or discrete but interconnected models. In the both cases for the purpose of this thesis, the term basic integrated model (Figure 1) will be used. BI BIM serves as a keystone or basis for further populating by data of the higher order models such as 4D, 5D and nD. In this perspective BI BIM is still 3D BIM model containing only elementary data as stated in the first chapter.

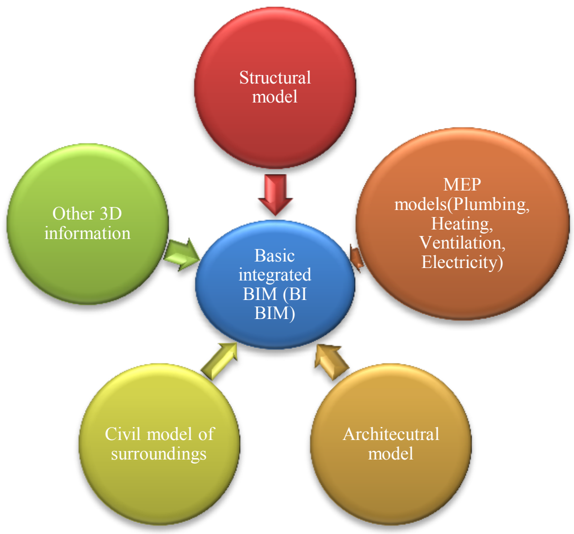


Figure 1 BI BIM - Basic integrated model

In perception of BI BIM as a keystone for the further nD model development, there are two different approaches in creation of nD models i.e. discrete modelling approach and integrated modelling approach which are in detail described in the Used methods chapter.

2.1 4D BIM

The building information model can be linked to schedules created in conventional scheduling software [18] [19]. In this way, a new dimension is added to this merged model, which is why these models are often referred to as 4D models because the geometric model of the building has been supplemented by a time dimension. Model 4D enables simulation and optimization of the construction process by sequencing and testing different scheduling options directly in the model environment. The 4D model can be displayed in the unfinished phases at individual times or time periods [19] (Figure 2). This allows modelling and virtually testing and optimizing variants of the construction process with regard to its constraints, investor requirements, or even the technologies used. This area of application includes planning of site equipment at various stages of construction, screening of complex technological processes and the also may be use and optimization of lifting equipment. [20]

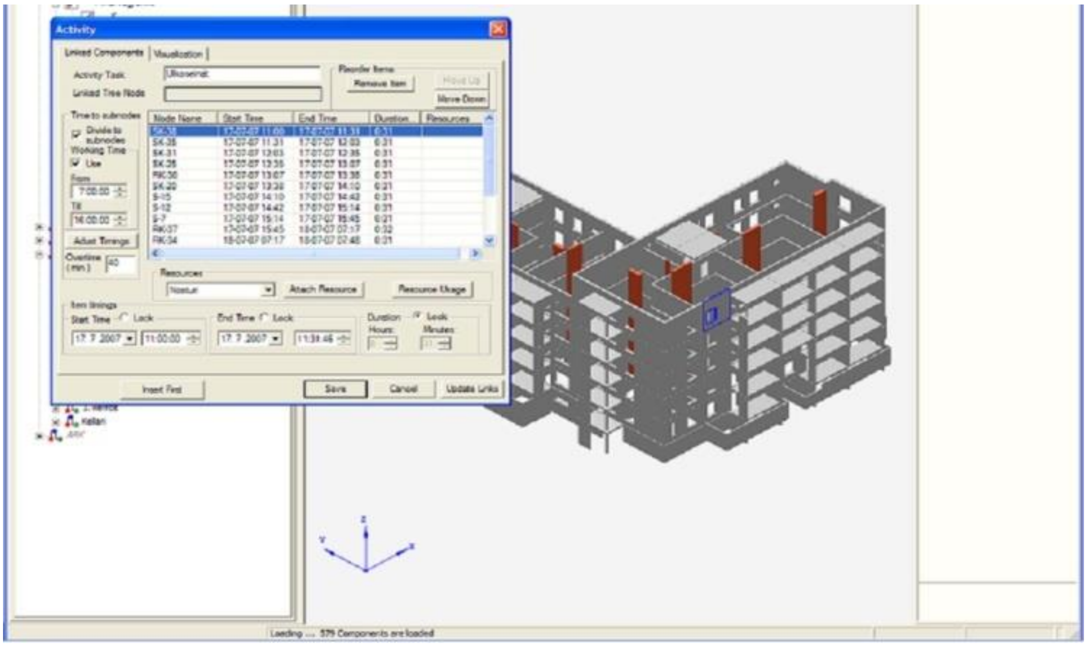


Figure 2 Sample of 4D model

All parties involved can use the 4D models to introduce the process, the intended construction process in a visually understandable and clear way. Furthermore, thanks to the possibilities and information already contained in the 3D model, the amount of material and the amount of work performed over time can be checked.

Nowadays, this is done manually with a high amount of time, due to the high amount of labour for linking the individual BIM models to the processes of the separately created time schedule. Another important fact is that the models must be often modified for this purpose to match the technological division of the stages, because models as such are not created with regard to technological planning and use as a basis for 4D modelling.

2.2 Model 5D – Finance

When linking 4D models to the budget, a complex time and financial model is created and is referred to as 5D due to the delivery of the fifth information dimension. The issue of drawing up assessment reports and budgets is also closely linked to this issue.

The use of BIM models to produce bill of quantities has clear advantages as well as limitations. In general, models can only be reported as much as they are inserted into them with appropriate accuracy. From information models, only up to 70% of the information needed to create a budget can usually be reported with high accuracy [16]. It is then necessary to add the remaining information manually or to calculate it from other documents.

When budgeting from BIM models, it is more important to know what is not included in the model rather than what the model contains, as everything else can be reported using software tools. The amount of information contained in the model is directly dependent on the detail of the model. The main cause when information cannot be obtained from the model is either due to the low level of detail of the given model or due to the different way the designer and the cost estimator work (such as scaffolding, transport of masses, etc.). However, due to the complexity of the detailed modelling work, it is not economically or time-efficient to create the BIM model with all the details needed to create a complete bill of quantities for the purpose of estimation of the cost. As mentioned above it is easier and more effective to calculate above mentioned items either from the items contained in the model or to include them into the aggregate [20]. Furthermore, the budgeting system used in the conditions of the Czech market is not adapted to create a budget from the building information model (Figure 3).

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
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
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

Figure 3 Sample of direct output from model

The benefits and simplicity of the automatic bill of quantities models are clear, but there is also a high risk of error in creation of the automatic bill from the BIM mainly due to the poor quality of model creation and inconsistency of data entered by the designer / model creator. Examples of errors in the model may be, for example, incorrect type or material designation of individual elements. Another risk is in the case of duplication of structures in the model (e. g. in the geometry of one wall is overlapping), another risk is the non-compliance with the agreed marking of materials, or the designation of the same material by different names (e.g. concrete, concrete, concrete, B20, C20 / 25, etc.). Many of these things can be eliminated by automatic or manual control of the models, but at the same time greater demands are placed on designers and "cleanliness" of their work.

Based on the above, it is necessary to classify the individual elements for reporting purposes and possibly link them to the estimating software. This was followed by manual transcription on the existing pilot projects, and the BIM model only served as a rich data source for separate bill of quantities extracted from the model only as a basis for future budgets.

2.3 On the classification systems

Classification of Structures and Works used in the Czech Republic (TSKP – Třídník stavebních konstrukcí a prací), which is based on price systems delivered in public tender proposals by engineering companies. These data are regularly maintained by the state that hires 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 modelling in the information model would be lengthy, impractical and would require designers to have cost estimation principles knowledge. Types are for example surcharges for work at heights, dusty environment, etc. That is why in many countries these classic classification systems are replaced by new ones, such as Uniclass (UK), OmniClass (USA), CoClass (SWE) [21] or eventually local or company specific classification systems.

As stated by ISO in the text of ISO 12006-2, "Provided that each country uses this framework of tables and follows the definitions given in this standard, it will be possible for standardization to develop table by table in a flexible way. For example, Country A and Country B could have a common classification table of e.g. elements, but different classification tables for work results without experiencing difficulties of 'fit' at the juncture [22].

The CONTEC method and system was originally designed to obtain and utilise data from Czech standard budgets and bills of quantities where 8-digit numerical code derived from TSKP [23] is being used to identify and classify the item in the budget. However, CONTEC is designed to be capable to operate with higher level of aggregation of individual items, where just first three or four digits are essential to classify the item together with related information such as description, quantities, quantity units and for that feature was selected as a tool capable to interconnect to the various coding systems used in BIM models. This aggregation respects the construction technology point of view, too, because the aggregation is done into construction processes as works of different work gangs on site, while the last digit of the code of the item means the technological stage, in which the construction process is implemented

2.3.1 The Omniclass [22]

The OmniClass Construction Classification System (known as OmniClass or OCCS) is a means of organizing and retrieving information specifically designed for the construction industry. OmniClass is useful for many applications in

Building Information Modelling (BIM), from organizing reports and object libraries to providing a way to roll up or drill down through data to get the information that meets your needs. OmniClass draws from other extant systems in use to form the basis of its Tables wherever possible — MasterFormat™ for work results, UniFormat™ for elements, and EPIC (Electronic Product Information Cooperation) for products

OmniClass is designed to provide a standardized basis for classifying information created and used by the North American architectural, engineering and construction (AEC) industry, throughout the full facility life cycle from conception to demolition or reuse and encompassing all of the different types of construction that make up the built environment. OmniClass is intended to be the means for organizing, sorting, and retrieving information and deriving relational computer applications.

OmniClass consists of 15 hierarchical tables, each of which represents a different facet of construction information. Each table can be used independently to classify a particular type of information, or entries on it can be combined with entries on other tables to classify more complex subjects.

OmniClass is, in simple terms, a standard for organizing all construction information. The concept for OmniClass is derived from internationally-accepted standards that have been developed by the International Organization for Standardization (ISO) and the International Construction Information Society (ICIS) subcommittees and workgroups from the early-1990s to the present. ISO Technical Committee 59, Subcommittee 13, Working Group 2 (TC59/SC13/WG2) drafted a standard for a classification framework (ISO 12006-2, more information below) based on traditional classification but also recognized an alternative "object oriented" approach, which had to be explored further.

ISO TC59/SC13/WG6 developed an electronic framework (ISO/PAS 12006-3, more information below) for the tagging and managing of objects and their attributes.

These standards, ISO 12006-2: Organization of Information about Construction Works - Part 2: Framework for Classification of Information, and ISO/PAS (Publicly Available Specification) 12006-3: Organization of Information about Construction Works - Part 3: Framework for Object-oriented Information, define methods of organizing the information associated with construction and affiliated industries, and also promote a standard object-modelling definition for concepts addressed. Of these two standards, ISO 12006-2 has more immediate impact on

OmniClass, and the OCCS Development Committee has closely adhered to this standard in establishing and defining the tables that make up OmniClass.

The Construction Industry Project Information Committee (CPIC) of the UK which was formed to create Uniclass has, to date, exploited this standard most successfully by publishing a usable version of Uniclass in 1997. It is anticipated that the UK authors will assess OmniClass as they work to update to that publication.

In addition to the application of ISO 12006-2 in Uniclass, the object-oriented framework standardized by ISO/PAS 12006-3 has been adopted by ICIS members in their Lexicon program, and both standards are followed by groups in several other countries that are developing similar classification standards, including Norway, Netherlands, UK, and others, in concert with the Nordic chapter of the International Alliance for Interoperability (IAI), and the Japan Construction Information Centre (JACIC) which is currently working to develop the Japanese Construction Classification System (JCCS), modelled in part on OmniClass.

The OmniClass Construction Classification System (OCCS) Development Committee believes that following these ISO standards will promote the ability to map between localized classification systems developed worldwide. It is the Committee's hope that organizations in other countries pursuing initiatives similar to OmniClass will also strive to be ISO-compatible, thereby enabling smoother exchange of information between them.

ISO 12006-2: Organization of Information about Construction Works - Part 2: Framework for Classification of Information: This standard provides a basic structure of information about construction that is grouped into three primary categories composing the process model: construction resources, construction processes and construction results. These are then divided into fifteen suggested "Tables" for organizing construction information. The OmniClass Tables correspond to this arrangement of information:

- Tables 11 - 22 to organize construction results
- Tables 23, 33, 34, and 35, and to a lesser extent 36 and 41, to organize construction resources, and
- Tables 31 and 32 to classify construction processes, including the phases of construction entity life cycles.

ISO/PAS 12006-3: Organization of information about construction works - Part 3: Framework for object-oriented information implements the basic approach of

ISO 12006-2 but uses the entries on these tables as the defining points (or characteristics) for object-oriented information organization. The ‘object-oriented’ approach describes the characteristics of things without imparting a grouping preference or hierarchical order.

In the object-oriented approach, the object is central, acting as a basis for characteristics or properties that describe it. An object thus described can then be grouped with similar objects using a classification arrangement like OmniClass. The framework established by ISO/PAS 12006-3 will enable computers to store and relate information in an object-oriented manner, while OmniClass Tables provide humans with a variety of viewpoints to that data, and a useful approach to establishing relationships between objects.

For the purpose of this thesis Table 21 Elements respectively Table 22 is applicable classification systems which might be utilised for the data transfer and for the purpose of the thesis as a base for a coding system. The Omniclass was evaluated during the research predominantly due to the fact, that Omniclass is fully integrated into the software Autodesk Revit, which is the most dominant software used to create BIM models in the Czech Republic.

2.3.2 The Uniclass 2015 [6]

Uniclass 2015 is a unified classification for the UK industry covering all construction sectors. It contains consistent tables classifying items of all scale from a facility such down through to products. Uniclass 2015 is a unified classification system for the construction industry. For the first time, buildings, landscape and infrastructure can be classified under one unified scheme.

- A hierarchical suite of tables that support classification of all ‘things’, from a university campus or road network, to a floor tile or kerb unit.
- A system compliant with ISO 12006-2 Building construction — Organization of information about construction works Part 2: Framework for classification and also allows mapping to other classification systems in the future.
- A classification system maintained and updated by NBS.

Uniclass 2015 is divided into a set of tables which can be used to categorize information for costing, briefing, CAD layering, etc. as well as when preparing specifications or other production documents.

2.3.2.1 Uniclass Tables

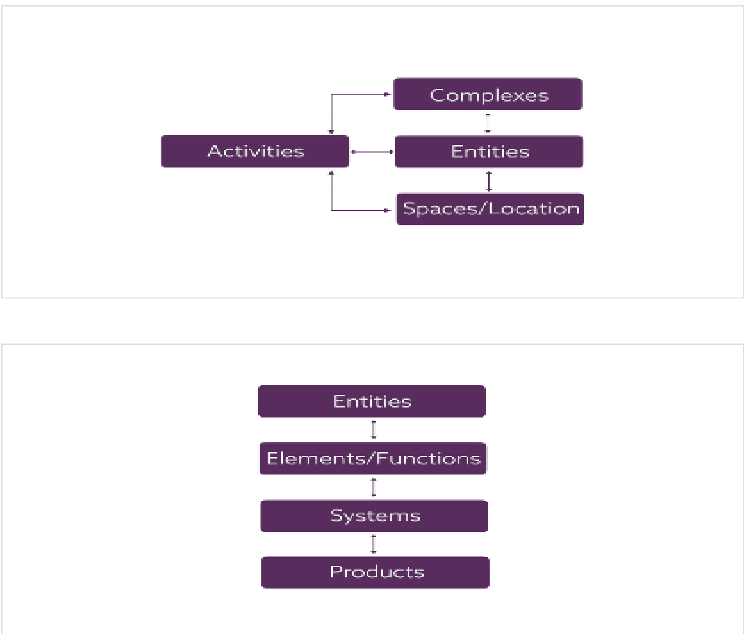
The suite of tables is broadly hierarchical (Figure 4) and allows information about a project to be defined from the broadest view to the most detailed. The Complexes table describes projects in overall terms and can be thought of in terms of the provision of an Activity. Complexes can be broken down as groupings of Entities, Activities and Spaces/ location depending on the use.

Entities can be described using the Spaces/ location and Activities tables if required. The linear Entities can also be described using the Systems table.

For detailed design and construction, the main starting point is Entities.

The main architectural components of an Entity are Elements, such as roof, walls, floors, etc. Other requirements in an Entity, such as drainage, heating or ventilation, are included as Functions which are part of the Elements table which is named Elements/ functions. Functions can be used in the early stages of a project to define what services are required but can also be used to describe facets of an asset manager's role for managing these services or functions.

Elements and Functions are described in more detail by Systems which in turn contain Products.



Uniclass 2015 - Complexes, Entities, Spaces/Locations and Activities tables

Uniclass 2015 - Entities, Elements/Functions, Systems and Products tables

Figure 4 Uniclass 2015 scheme

2.3.2.2 Using the classification system

The tables need to be flexible and to be able to accommodate enough coding's to ensure coverage, to allow for a multitude of items and circumstances, including new technologies and developments that are yet to emerge.

Work is being done to support the tables and their users: synonyms are being added to terms to aid searching, and mappings to other classification systems are being prepared, to allow a seamless cross-over.

Each code consists of either four or five pairs of characters. The initial pair identifies which table is being used and employs letters. The four following pairs represent groups, sub-groups, sections and objects. By selecting pairs of numbers, up to 99 items can be included in each group of codes, allowing plenty of scope for inclusion.

For example, Systems are arranged in groups with subgroups which are sub divided, which leads to the final object code.

- 30 Roof, floor and paving systems
- 30_10 Pitched, arched and domed roof structure systems
- 30_10_30 Framed roof structure systems
- 30_10_30_25 Heavy steel roof framing systems
- 50 Disposal systems
- 50_75 Wastewater storage, treatment and disposal systems
- 50_75_67 Primary sewage treatment and final settlement systems
- 50_75_67_46 Lamella tank systems

2.3.1 TSKP based CONTEC classification system [24]

The activity database, together with the resource code, forms the overall databank of standard data on activities with a common use of at least one group of type network graphs to build a construction technology design. The purpose of the activity databases is to collect normative data for the individual database items (activities – as construction processes) that are needed to calculate, in particular, the duration of processes in future preparatory documents. It follows that the activity database must be present when processing the basic Construction technology design documents. The basic type of database contains activities at the level of partial construction processes, also called activities, building parts or non-aggregated activities as work of several work-gangs on the building site in actual technological stages. Such a database is implicit in area 1 of the

CONTEC® system. The three main files of this database have a common prefix of "DB" and are stored in the Data base folder. The database consists of activities that are identified by numerical and verbal code, each activity contains several descriptive and normative entries and a reference to up to 20 resources.

The database of activities at the level of partial construction processes was created on the basis of classifying for building parts and crafts, eventually to the types of construction or subgroup of works, according to the class of building constructions and works [23]. With regard to the TSKP, the names of the activities, units of measure, numbering and distribution of the type of activity were roughly determined for the main and auxiliary construction production.

Classification system is created based on following principles based on TSKP which divides construction and work for construction production into 9 groups of building parts based on construction processes, work gangs and technological stages:

1 EARTHWORKS

2 SPECIAL FOUNDING, FOUNDATIONS

3 VERTICAL AND COMPLETE CONSTRUCTION

4 HORIZONTAL CONSTRUCTION

5 OTHER COMMUNICATIONS

6 FINISHING OF SURFACES, FLOORS AND ASSEMBLY OF OPENINGS

7 CONSTRUCTION AND FINISHING WORKS (including MEP)SBP

8 PIPE LINES

9 OTHER CONSTRUCTIONS AND WORK, CUTTING, SCAFFOLDING, TRANSFER OF MASSES

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 WALLS SUPPORTS AND LOOSE

32 WALLS 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 to 95 and case 979. For the other groups, the designation of activity is zero in the third place. So, the first three places of the label may look like. As follows:

3 VERTICAL AND COMPLETE CONSTRUCTION

31 WALL SUPPORTS AND LOOSE

310 WALL SUPPORT AND FREE WALLS

Or:

7 CONSTRUCTION AND WORK OF PSF

71 INSULATIONS

713 ISOLATION THERMAL INSULATION

The fourth character refers to the technological stage (TE). In theory, each group of the first three characters can bind to any technological stage. 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 according to the flow of implementation of a construction project and its parts (facilities).

Following are technological stages (TE) of the buildings [25]

0. Earth works + demolitions
1. Foundations
2. Sustructure
3. Superstructure
4. Roof
5. Execution of partition walls and 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

Therefore, a case of a type activity should not appear:

1404 MINIG ROOF...

A technological stage is a group of structures and works defined with regard to time and area of implementation. Classification of activities according to TSKP allows to use the division of Construction 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.

Examples of the whole designation of activities:

3 VERTICAL AND COMPLETE CONSTRUCTION

31 WALLS BEARING AND FREE STANDING

310 WALLS BEARING AND FREE STANDING

3102 WALLS BEARING BASEMENT

3103 WALLS BEARING

3104 WALLS ABOVE ROOF

3105 SYSTEM CHIMNEYS

3106 WALLS SUPPORTING

3109 CORNICES

or:

7 STRUCTURES AND WORKS - FINISHING

71 INSULATIONS

713 THERMAL INSULATION

7130 REMOVING OF INSULATION (ANY TYPE)

7133 FIREPROOF INSULATIONS

7134 THERMAL INSULATION OF ROOFS

7135 THERMAL INSULATION HEATING

7136 THERMAL INSULATION INTERIORS (floors, walls, ceilings, girders)

7139 THERMAL INSULATION EXTERIORS (walls, ceilings, pipes)

There are also some activities in the database that are not a direct part of the TSKP classification, but logically fit into it, e.g.:

9003 OTHER WORK TE 3

904A SEPARATE BASIC ITEMS

905A OTHER costs, reserve

The measurement units of activity correspond (with small exceptions) to the TSKP, as well as the division of activities into MBP (Main building production) and SBP(Secondary building production) This distinction is simple when binding to TSKP, as all the work of SBP is contained in the group of building parts 7. All other groups fall under MBP.

The activity database also contains another classifier category that does not bind to the TSKP. This is a 5-digit word key. It contains any 4-character abbreviation supplemented by the number of the technological stage. By the word key it is possible to quickly search for an activity without knowing its number and it also serves for a brief description of the process when plotting the line-of-balance.

Example:

7134 IZTE4 THERMAL INSULATION OF ROOFS.

2.3.2 BIM based classification systems in the Czech Republic

In the Czech Republic, the situation develops very rapidly, when, since the first BIM conferences in 2010, despite the realization of the first pilot projects at the end of the year 2013, there is a clearly defined requirement of the market for standardization, which is currently under patronage of non-profit organization CZBIM.org, where development of Czech based classification started. However, the situation is somewhat more complex, and this is demonstrated by the following example of the organization CZBIM.org, which is at this moment the most important group promoting BIM in the Czech Republic and as such brings together the most important institutions.

From the perspective of future BIM developments, the most important following two working groups of this organization:

PS # 01: BIM & Standards and legislation

Dealing with the continuity of BIM modelling to the European Directive, respectively, of Building Information Modelling (BIM) on Directive 2014/24/EU of the European Parliament and of the Council.

However, which did not advance the definition of project requirements and the definition of the building models at the time of the writing of the thesis.

PS # 03: BIM & Realization

Main objectives

- Defining and assigning LOD (Level of detail) to individual stages of project documentation
- Create a unified data structure for BIM in the Czech Republic
- Creation of contractual standards for ordering architectural and projection work, realization of construction works, and managers and operators of constructions processed in BIM technology for building construction
- Enforcement of contract standards on the CZECH market

In this group both major construction companies (Metrostav A.S., Skanska a.s., VCES a.s.), representatives of design companies (Obermeyer HELIKA a.s.), Producers of budgetary software (ÚRS Praha a.s., Callida s.r.o.) and consultants are represented.

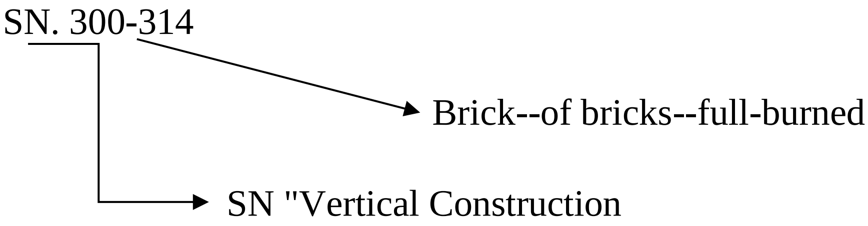
Since this group brings together significant companies in the market for land and transport construction as well as budget companies, it can be assumed that the agreed output will be accepted as a national standard in the future.

2 concepts were developed within the group and are under process of testing, i.e. SNIM [26], URS system [23].

2.3.3 CZBIM – SNIM System

An example is in annex 4a, B – it is a modified system, at this moment the most discussed in Group 2 CZ BIM. This system enables rapid implementation on the pilot project, within the Czech Republic, so far the widest support among designers, because it is based on the software system of marking of MEP and HVAC components and is simply applicable for building objects. It also provides some possibility of variability for defining specific structures

The syntax then works as follows:



The range of numbers 300 to 314 then enables to encode the design specifically for the design and the required modifications in the design.

This system is already piloted by Obermayer Helika and follows the data structure accepted for Skanska a.s.

For the above reasons, and then because of the availability of models for testing the interconnection, this system is best suited for the development of the connection between the CONTEC and BIM.

2.4 On methodology and basic documents of the construction technology design [27]

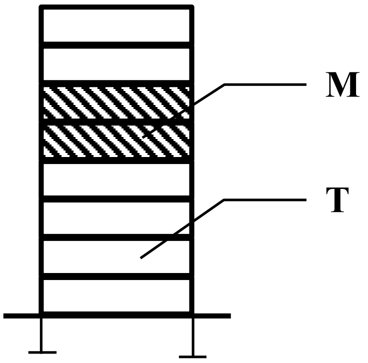
The main documents in construction technology design include files of technological standards, sometimes called as technological analysis sheets or programs, and network diagrams. The close link between these documents which is used in the CONTEC expert system enables to elaborate bar charts, line-of-balance graphs, allocation graphs of different technological and economic resources and quality assurance checklists. Hitherto the said documents, on one hand technological standards (programs) and on the other hand network diagrams were mostly processed subsequently, separately. Their close construction technology relationship was often disregarded, and network diagrams elaborated without consistent technological analysis and synthesis contained a number of errors which made them useless for construction project control with all consequences thereof, regarding economical, time and quality losses. Quality assurance checklists were not usually elaborated at all or by a separate division with no connection to the actual flow of the building process. The simultaneous elaborating of technological standards, network diagrams, cost analysis and quality assurance checklists, used in the CONTEC expert system, eliminates the processing of network diagrams without the technological analysis and synthesis and makes possible to use the close link between technological standards and documents for quality management in the project. [27]

The technological standard (technological analysis sheet or programme) determines the technological structure of the production process (sequence of construction processes, volume of production, labour and cost consumption, number and profession of workers or machines etc.). According to the calculated network diagram the technological standard includes a bar chart which indicates the time structure of the production process. Further a technological scheme showing the spatial structure of the process is usually added. The connection between the time structure and the spatial structure of the building process can be seen in the line-of-balance graph. The quality assurance checklist which is automatically created according to the technological standard consists of instructions for performing the quality checks of the resulting product at every significant construction process.

According to the values of the duration of the processes and the minimum working space necessary it is possible to determine (with regard to the direction of the course of processes) the critical approximation of construction processes and to link these processes immediately in the optimum way in the construction technology network diagram method with regards to the condition of the quality of the resulting products of construction processes. Thus, all documents mentioned above after the network diagram calculation depict floats of the construction processes. Floats are subsequently used for the optimization of the building process from the point of view of limited resources in different time periods. [27]

2.5 Basic fact on links in the construction technology network analysis method [27]

The construction technology network analysis method used by the expert system was designed for simultaneous evaluating of technological standards and network diagrams and for the optimization of linking the construction processes from the point of view of maximum use of minimum working space on site necessary for the efficient, economical and safe performing of construction processes including technological pauses [28]. This network analysis method uses the activity-on-node network diagram. All four types of links of activities introduced in the precedence graph method (finish - start, start - start, critical approach and finish - finish), [29], are included in the construction technology network analysis method too. The main disadvantage of the precedence graph method is the necessity to know the actual values of lag times between every two activities that are linked together and their duration while creating the network diagram. This would make the concurrent evaluation of the technological standard and of the network impossible.



M - minimum working space
T - total working space available
f - working space index

$$f = \frac{M}{T} \bullet 100 \quad [\%]$$

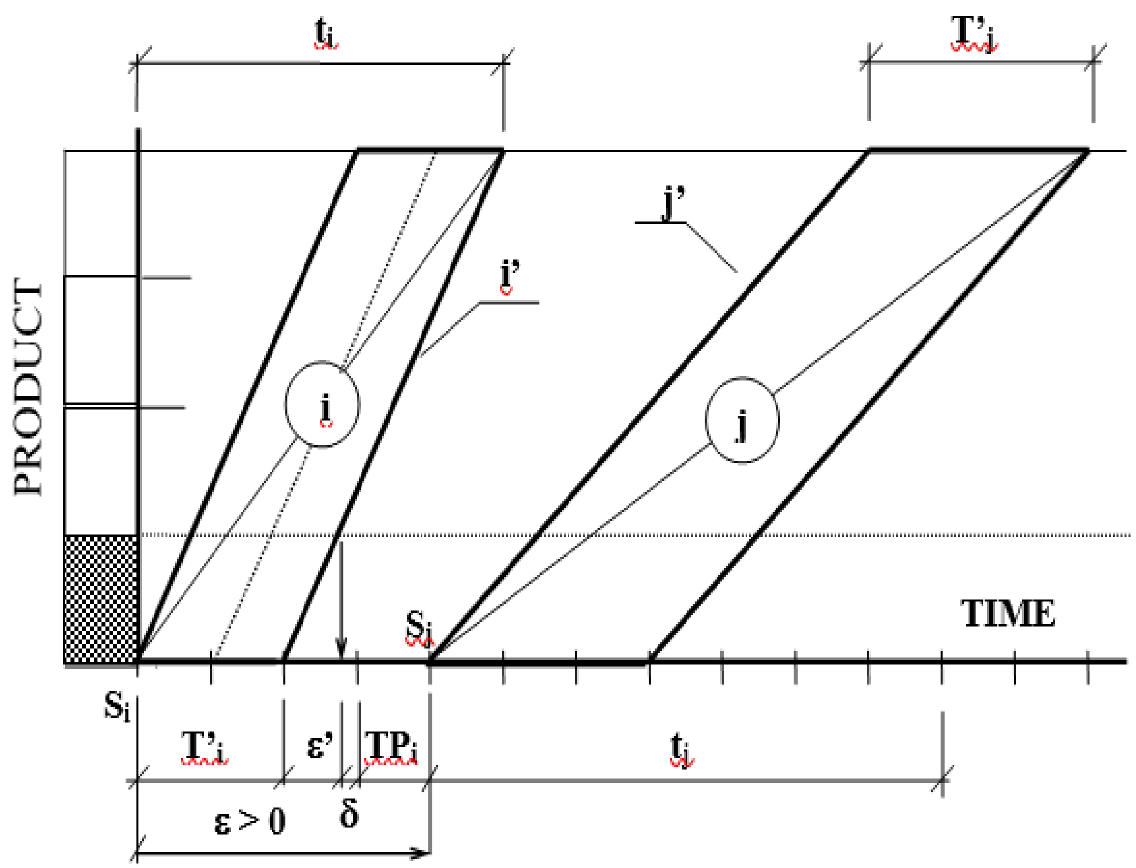
Figure 5 Working space index

Therefore, the construction technology network analysis method introduces the 5th type of link, the construction technology link, that results from the condition of release of the minimum working space on a structure by the previous work gang so that the following work gang could start as soon as possible. The lag time is not given by a certain time value, but it is calculated by the computer according to the duration of linked activities and to the spatial structure of the building, which is represented by a working space index f. This index is determined by the ratio of the minimum working space needed for the gang divided by the total working space in the building, e. g. in a 8 story administrative building the usual minimum working space are 2 floors, so the working space index f is 2/8, that is 25 %, see Fig. 3. Introducing this link in the CONTEC method means not only a simplification of inputting the data of the network diagram but it permits a wide formation and utilization of typical network diagrams as computer files for the erection, maintenance and reconstruction of different sorts of buildings with the possibility of their modification according to the spatial structure of the actual building. There are usually only three main types of working space for different activities on site (f_1 for sub terrain structure or works on the roof, f_2 for erection and plumbing, f_3 for finishing works). Thus, only three values of the main working space indexes are sufficient to evaluate practically all technological constraints in the building process. In the typical network diagram, the values of the working space indices are given parametrically. While stating data about the actual building the typical network diagram can be modified by stating of the 3 main working space indices only.

The situation of linking two processes of technological stage i and j is illustrated in the line-of-production graph on fig. 2 a, b. Each process of technological stage (e. g. foundation, superstructure etc.) consists of several construction processes (working gangs, e. g. formwork, reinforcement, concrete laying etc.). Values t_i and t_j represent the duration of processes of technological stage, T_i and T_j their time of launching, TPi the technological pause after completing the i activity, f_{ij} is the working space index. In the first case (fig. 2 a) if the last construction process in the preceding process of technological stage i is shorter, than the first construction process in the following process of technological stage j, the lag time ε can be automatically calculated according to formula (1).

$$\varepsilon = (t_i - T'_i) .f_{ij} + T'_i + TP_i + \delta \qquad (1)$$

a) $(t_i - T'_i) \leq (t_j - T'_j)$



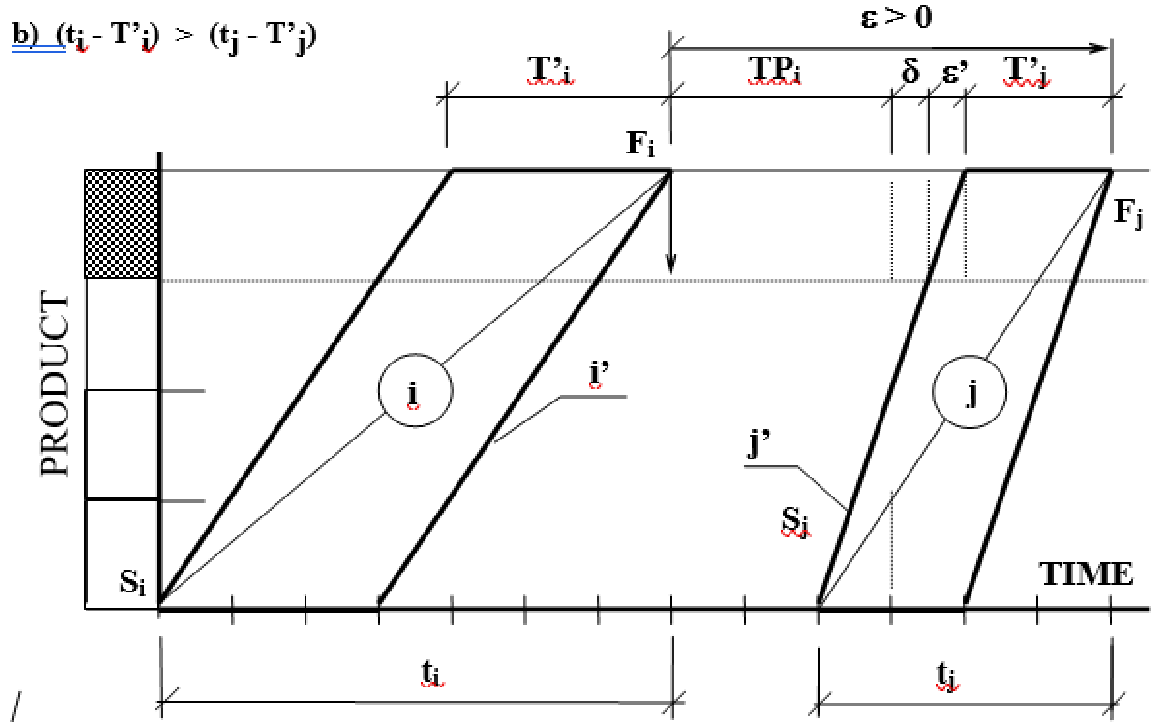


Figure 6 Principle of the construction technology link

The δ value rounds the lag time to whole time units, so that the topical work gang would start their work at a certain time unit in the morning. If the first construction process in the following process of technological stage j is shorter than the last construction process in the preceding process of technological stage i, (fig. 4 b) then the lag time ε is calculated according to formula (2).

$$\varepsilon = (t_j - T'_j) .f_{ij} + T'_j + TP_i + \delta \qquad (2)$$

In the time analysis of the network diagram using the construction technology link, the start of the following activity j S_j can be calculated during the forward calculation according to formula (3), the finish of the preceding activity i F_i can be calculated during the backward calculation of the network diagram according to formula (4).

$$S_j = \max \{[S_i + (t_i - T'_i) .f_{ij} + T'_i + TP_i + \delta)]; [S_i + t_i - t_j + (t_j - T'_j) .f_{ij} + T'_j + TP_i + \delta]\} \qquad (3)$$

$$Fi = \min \{[Fj - tj - TPi + (1 - fij) .(ti - T'i) - \square]; \; [Fj - T'j - TPi - fij .(tj - T'j) - \square]\} \qquad (4)$$

Further, the construction technology network analysis method introduces the 6th type of link, the flow link, that results from the condition of continuous course of a construction process on different products, e. g. sections, buildings etc. The 7th and 8th types of link, the partial links, describe the condition that a following activity can start (or must finish) after the completion of a certain part of the previous activity or vice versa. These links are determined by the partial link indices that represent the ratio of the duration of finished part of the previous activity divided by the total duration of the previous activity (type 7) or the ratio of the duration of unfinished part of the following process divided by the total duration of the following process (type 8). If this index is negative it represents the same ratio but for the following (type 7) or preceding (type 8) activity. Using the flow link modified typical network diagrams or evaluated network diagrams of buildings can be automatically linked into a greater network that may represent the building process of the whole project consisting of more buildings, e. g. a housing estate, an industrial plant, or its maintenance or reconstruction. In this case the flow links are generated by the system at activities that are performed by specialized work gangs that proceed continuously from one building to another.

The network diagram can be calculated on the deterministic or stochastic base, [28].

Chapter 3 Targets of the thesis

The target of this thesis is to introduce means of automated creation of nD BIM models [14] as stipulated in above chapters. Focus will be placed not only 4D and 5D but also 6D Plan of resources, 7D Quality plans 8D Environmental risk plan 9D Health and safety risk plan etc. For the purpose of this thesis, all models above 5D will be called models of higher order or nD.

In order to achieve this goal existing data included in the BI BIM models will be utilized as a base data to for the existing software CONTEC expert system, which was originally developed for automated creation of the basic documents of the construction technology design as described in [30].

CONTEC was originally developed to work with data included in the schedules organized in the form of budget. The aim of this thesis is to define means of data transformation from the BI BIM into the CONTEC and to create data of the construction technology design based on BIM data. By interconnecting of these data sets models of a higher order would be created.

The aim define means of data transformation for automated creation of nD models and by this means to improve the productivity of the construction management works. Successful solution of this problem would enable early evaluation of constructed buildings with respect to the level of development of a BIM model, providing information about the construction time as well as rough estimation of construction cost in the preparation phase. In the execution phase utilization of this approach shall create complete set of construction technology design documentation.

By use of existing phenomena i.e. fast development of the BIM design, continuous research on classification systems [21] [6] [23] [22] in combination with existing proven software solution [29] a new method will be created.

The developed method will be applied in two modification i.e. direct application of coding into the model and creation of transformation database of a general coding system into the CONTEC system.

The created documentation will be compared with the documentation and construction times on the executed projects with regard to the documentation in a case study as well as to the real construction times of selected projects. Work proceedings will be as shown on Figure 7.

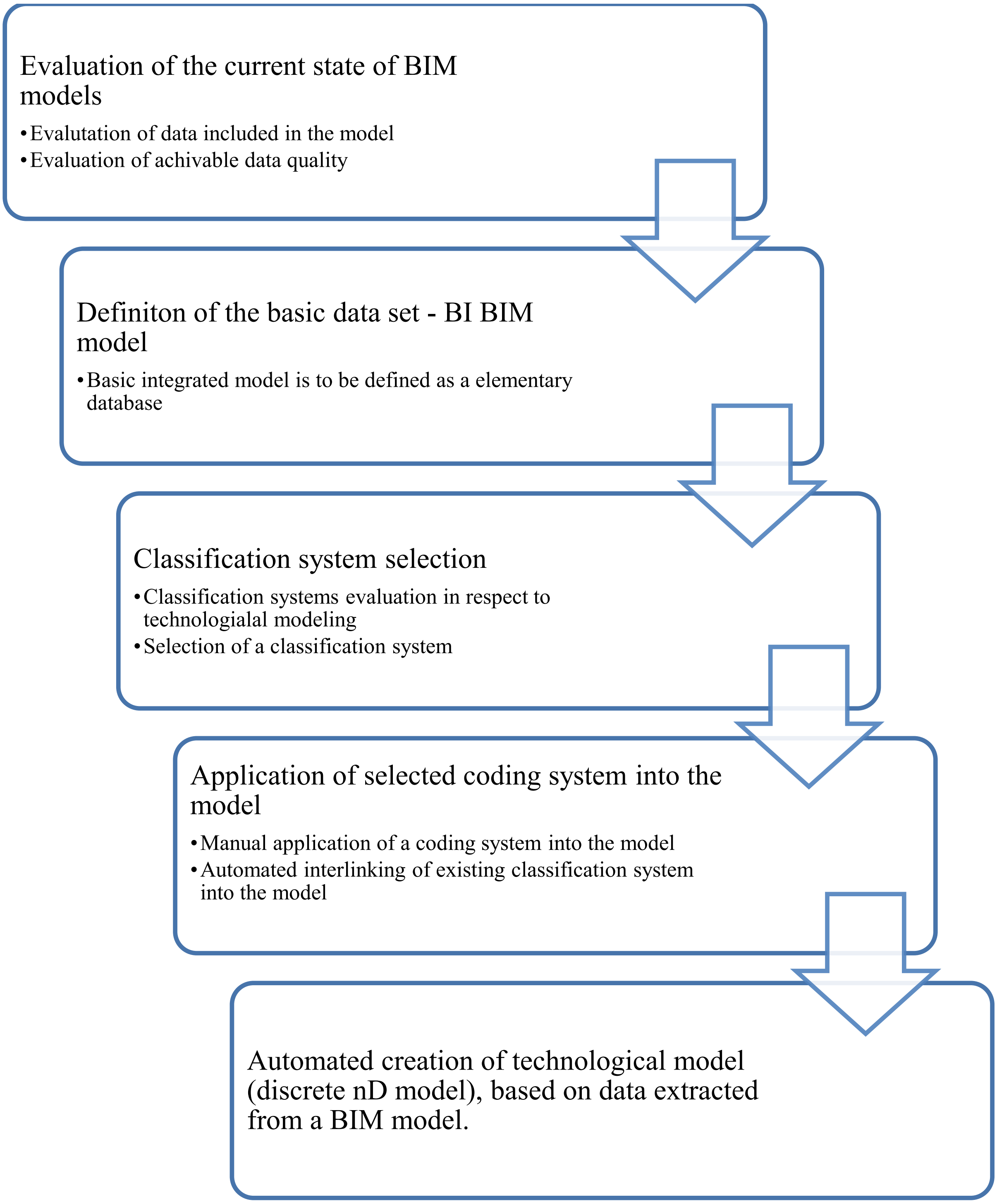


Figure 7 Diagram of work phases

Chapter 4 Used methods

In my thesis following methods are used

- Analytically-synthetic method of the scientific work
- CONTEC Method [31] [32] [33]
- Integrated modelling approach in BIM
- Discrete modelling approach in BIM

4.1 CONTEC Method

4.1.1 Basis of the STSG Method

“(STSG Stavebně technologický síťový graf)” – Construction technology network diagram was originally developed for automated computing of technological analysis and network diagrams and is utilised in the CONTEC expert system [29], [30], [34] STGS is based on BKN method (Baukasten Netzplanung) [35]. The activity-on-node network diagram used by STSGis in compare with BKN, where only 4 types of technological links are used, expanded by four other types of a links as follows: construction technological link, enabling optimal interlinking of processes with respect to the spatial consequences and ensures a condition of use of the minimum working space for a work gang. Furthermore, sixth type of a link is a flow link, which ensures condition of fluency of the works engaged in the flow of one work gang engaged on the various tasks on several facilities or parts of a building. The seventh link is the partial start - start link and the eight links is the partial finish - finish link enabling linking of the term of start of the successor to the partially finished predecessor process or the term of start of predecessor process can be linked to the part of a completed successor process, or that part of the predecessor process will be finished after the finish of the successor process [36].

As proposed in the published papers [37], [38] data from the BIM model can be harvested and transformed into so called nD models. Two main approaches were considered where data were integral part of the BIM model and second where interconnected specialized models were created.

4.1.2 Time analysis of the network diagram in STSG

Time analysis is in STGS method is governed by the same principles as other classical methods of the network analysis.

By forwards calculation the terms of early start and finish of individual tasks are calculated. First early start of i^{th} task ZM_i is determined as maximum of 8^{th} partial first early starts of a i^{th} task $ZM_i^{(k).}$ Evaluated are only tasks where i^{th} task is linked with the link type k:

a) k=1, type finish start (K-Z)
b) k=2, type start-start (Z-Z)
c) k=3, type critical approach (KP)
d) k=4, finish – finish (K-K)
e) k=5, construction technological link(STV)
f) k=6, flow link(PRV)
g) k=7, partial link start start(ČZZ)
h) k=8, partial link finish finish(ČKK)
i) ZN – external forced start

Similarly backward calculation of the late terms may be performed.

4.2 Integrated modelling approach

Integrated models are being created by means of populating BI BIM model by required data i.e. time (4D), cost (5D), other (nD). Above-mentioned data are than 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 etc. in case of the cost information.

In most of cases is populating of the information related to more than property of the object and for that reason in order 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 as an integral part of the BIM database.

Apparent advantage of this approach is creation of single database containing all necessary data for all intended purposes stated in the BIM execution plan (BEP) [4]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 combination of purposes as well ensures up to date state of the data, i.e. data are as current as the model itself. Data organization can be visualized as an expanding layers of BI BIM model creating subsets of complete model database (Figure 8).

Disadvantage of this approach is the high data volume which has to be processed, even though it might not be needed at the given moment for the intended purpose. Due to the high demand of this approach on computing power and data clarity and conformity is this approach preferably used on small scale projects, where data volume and therefore also reaction time of the software using the BIM data on the standard computers is on acceptable level.

For the models of higher complexity is this approach at the current state of software and hardware development contra productive not only in perception of computing power but also due to high demand on data clarity and conformity through the various models. Furthermore, large databases are forcing the user to work with the data which might not be essential for the given purpose and therefore the speed data management and work effectiveness is affected (see survey in discrete modelling chapter).

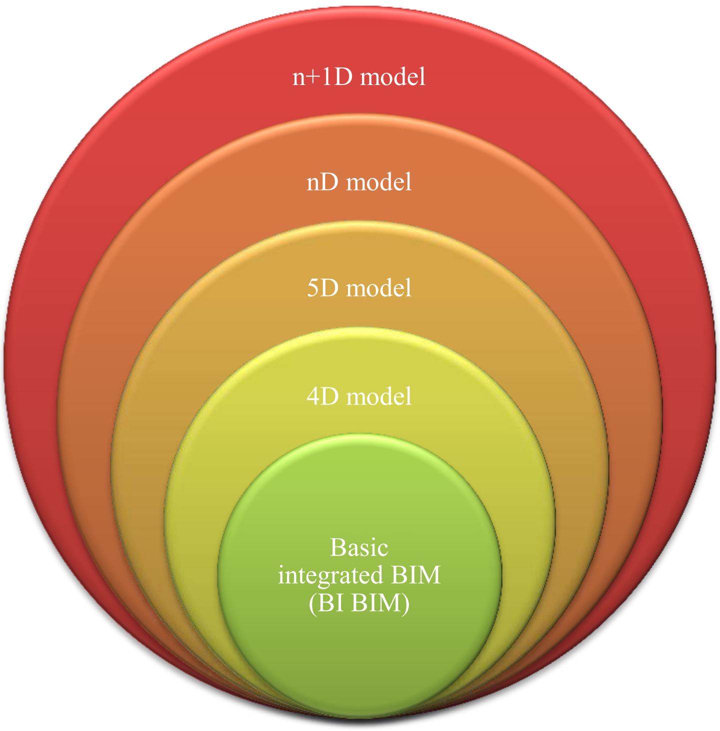


Figure 8 Integrated modelling approach

4.3 Discrete modelling approach

The discrete modelling approach utilizes either specialized but discrete models derived from the BI BIM, or discrete models or data sets directly linked to the BI BIM model. Discrete modelling advantages are mostly derived from the lower data volume and the fact that users may use just the data, which 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 work with high volume of data and with very complex models.

Furthermore, this approach is necessary when working with models of the large scale and therefore large data volumes. Based on working experience (Figure 9) is at the current level of the hardware development models acceptable size of the working models at around 200 MB.

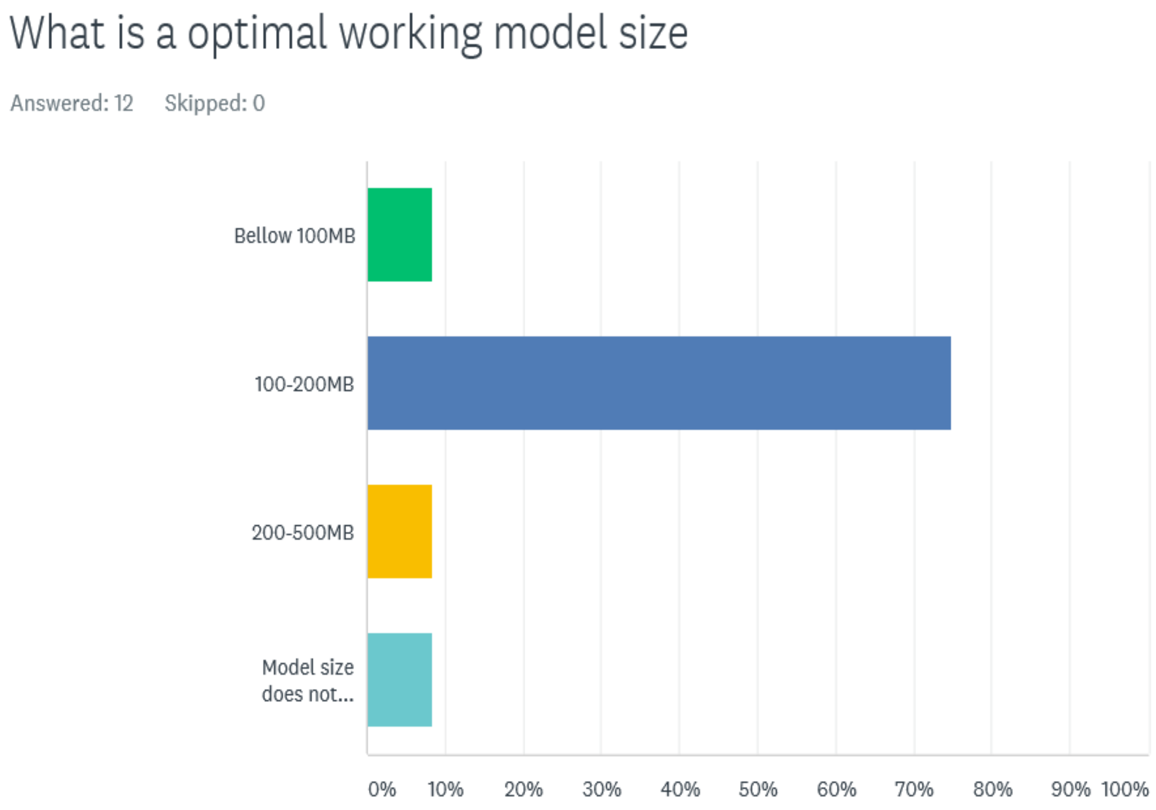


Figure 9 Research among BIM coordinators

Current design recommendation even for BI BIM models are that models are not to exceed 500 MB for each file (Figure 9)(Figure 10). In the case of large scale projects, are even BI BIM models split into number of discrete models. Either models are split spatially or based on trade/work package.

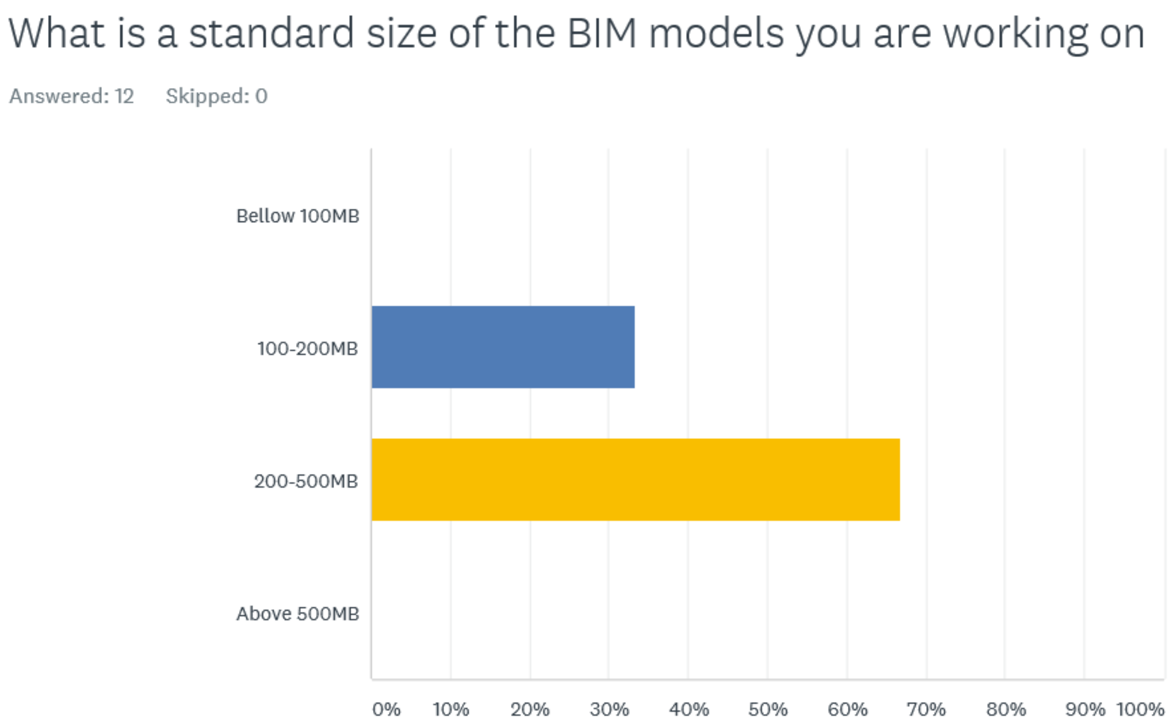


Figure 10 Research experience with BIM models

In discrete modelling approach, is the way of linking of the models or data sets a key aspect of correctness and usability of the discrete models, together with possibility of updates of information cross all discrete models.

Currently, apart from the split BI BIM models, model linking is at the most cases done indirectly by exporting necessary datasets from the BI BIM and developing or populating these data while working on the specialized model, this approach is utilized for example in the structural design or thermal calculations, where results of the discrete modelling and calculation are then in the necessary volume transferred back into the BI BIM model. These models cannot be perceived as true nD models due to the missing direct linking and update possibilities.

Other approach is the direct interlinking between discrete models and BI BIM models, which can be created either manually or semi manually by directly linking necessary data to the items or data in the BIM or in some cases automatically through existing coding systems. In this case data in the discrete model can be automatically updated when BI BIM is modified or changed.

This approach is used especially in case of 4D and 5D models, where current software systems are designed for this purpose. However, this thesis intends to demonstrate possibilities of automatized nD model development by means of interconnection of existing non-BIM software, in this case CONTEC, with the various BIM models through the coding interface. Through the CONTEC discrete output date 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 (6D) resource plan, (7D) quality assurance checklist and testing plan - KZP, environmental plan (7D), health and safety risk plan (8D) including schedule of risk occurrence (9D), as well as other data such as resource or various analysis's are then created.

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 in increasing the productivity in the construction process not only in the pre-construction phase but also in the execution of the works. This process is enabling transfer of the resources, increase of the focus of the project management staff from the process-oriented tasks such as manual planning, costing, creation of base health and safety registers and creation of quality assurance checklists to the improvement-oriented task such as optimization and maintenance of all above-mentioned tasks.

Above mentioned approach is applicable not only for discrete modelling approach, where dedicated models for specific purposes can be created but also is applicable for integrated modelling approach where reverse transfer of information to the BIM is needed by already developed methods.

Chapter 5 Results and solution

This thesis is based on the fact, that the BIM model is in fact a database of constructional information, containing not only the data needed for the 3D visualization of the database but other useful data such as material and quantities information, but also spatial information such as placement of individual items in the building etc. Every item in the database shall be classified by classification code, so that database can be processed or interlinked with other databases based on the used classification system either for the purpose of pricing of the model [21] or generally for the data processing.

5.1 Evaluation and selection of the classification system

Following systems were evaluated Uniclass (UK based system), Omniclass (US based system), SNIM CZBIM (newly developed local Czech system), Modified TSKP (Contec classification system)

5.1.1 Uniclass

5.1.1.1 Benefits of Uniclass

- is gradually integrated into BIM software due to the rapid development of BIM in the Great Britain
- It has until recently been promoted by the UK as a standard for future European legislation
- It is a numerical system with a clearly defined structure with links to various phases of the building process
- It is complex for both ground and transport construction
- It is connected to the standardization of the ISO system

5.1.1.2 Disadvantages of the Uniclass system

- Not compatible with systems used in the Czech Republic

- There is a political question to be enforced in view of the UK's exit from the EU
- Not extended to nearby markets (Germany, Poland, Austria)

5.1.2 Omniclass

5.1.2.1 Advantages of the Omniclass system

- Integrated into BIM software, such as the Revit Architecture
- is introduced in the United States - major world construction market
- enforced and required by companies with links to the US – significant in case of project divestment by developers.
- Pilot has been tested on projects in the Czech Republic

5.1.2.2 Disadvantages of the Omniclass system

- By default, US systems are more difficult to enforce on the market in Europe
- Very difficult to connect and interlink to the classification used in the Czech Republic
- Does not follow Czech pricing standards
- Hard to link to the technological stages (TE)

5.1.3 SNIM – CZBIM system

5.1.3.1 Advantages of the SNIM - CZBIM system

- System designed by Czech design company in accordance with design standard
- Easy to use for unexperienced users
- Fit to use with BIM model
- Pilot project already in execution phase
- As a new system it still possible to modify – influence development

5.1.3.2 Disadvantages of the SNIM - CZBIM system

- Does not match standard classification systems used in Czech Republic
- High level of aggregation in some cases
- Underdeveloped for MEP
- Generally rather simplistic

5.1.4 CONTEC (TSKP based system)

5.1.5 Advantages of the CONTEC (TSKP based system)

- System based on traditional Czech classification standards – easy to interlink
- Good level of aggregation for the purpose of use in the BIM models
- Pilot project already in execution phase
- Acceptable complexity

5.1.5.1 Disadvantages of the CONTEC (TSKP based system)

- Demanding for designers to put into consideration technological stages (TE)
- Units measurements have to be adjusted in some cases
- Generally, not wide spread among designers – yet based on standard classification.

5.1.6 Decision about the use of the system for the automated data transfer.

The fact that designers working with the BIM model are not accustomed to the creation of the bill of quantities and budgets (task by default performed by specialist), is one of the greatest obstacles in faster implementation of reasonable classification system into the BIM models.

CONTEC classification system was chosen for the pilot of the manual coding of classification system into the model. Decision was based on two premises:

1) Manual coding is performed after BIM model was created hence may be done by specialist who is familiar with implementation of project and the technological stages of particular works and with budgeting principles used in the Czech Rep.
2) Transformation of the data from the BIM database into the CONTEC does not require extensive conversions.

SNIM – CZBIM was selected for this thesis as one for testing of automated transfer, despite of the fact that it is not ideal for the given purpose, existence of the real project with applied SNIM system, was the main cause of the decision -. Neither Omniclass nor Uniclass was successfully applied in the Czech Republic on the executed projects or used for the export of the bill of quantities.

Furthermore SNIM – CZBIM system is open for editing, therefore it may be developed for the future use, based on the requirements stipulated by this thesis.

5.2 Automated nD model creation using CONTEC

Discrete modelling approach is selected in this thesis to demonstrate possibilities of automated nD model development, with utilization of the data harvested form a BIM model and processed in the CONTEC expert system.

To transfer information to the CONTEC software, the aggregation of the production calculation, the bill of quantities and the budget is used. The principle of preparation of data for takeover into a network graph consists in the necessity of aggregating detailed budget lines of production calculations, budgets or bill of quantities according to the technological division of labour on partial construction processes - activities, which demonstrate the works of work-gangs on the building site, occur in network graphs and express the progress of the work of individual work-crafts.

The construction technology division of labour is automatically determined, i.e. structural items are automatically assigned to the structures, which are produced by construction processes performed by work gangs [30].

The most important thing for transferring data from BIM is that the bill of quantities items is encoded from the BIM system by a unique alphanumeric code. It does not matter the form of this code, it should be limited by a certain number of characters, and the coding system should be in a certain way logical, as it is e.g. in TSKP. Several coding systems can be used. For the purposes of BIM models, after determining the coding system of individual entities, it is necessary to create a converter between the information database in the BIM model and the CONTEC software on the basis of the proline of individual elements of a statement generated from BIM and construction processes. On this, the CONTEC system is ready and it is possible to create the converter easily when transferring data from several statements of bills of quantities, estimates or budgets, as this matter is built on the self-taught principle. Furthermore, it is necessary to harmonize the transfer. By using the construction process models that will be created with the help of the CONTEC system, it is possible to achieve up to 9D BIM models including 3D project documentation, construction time process, number of employees, price, cost and other technological resources, quality control, environmental plans and OHS(occupational health and safety) plans, including monitoring according to actual implementation of the project with the possibility of updating all documents. This information would then be transferred to the models for facility management as required.

As stipulated in the targets of the thesis CONTEC enables to model construction processes of the buildings or infrastructure including the creation of schedule, budget, resource plan and bases of quality, environment and and health and safety management [39], [40]. Model creation works on principles of joining the methodology of construction technology design and original STSG network diagram method [31]. Due to the fact, that necessary data are available [24], the construction technology models of the implementation of a project can be created with high speed and considerably high accuracy.

CONTEC as an expert system is based on quick modelling of the building process, maintenance or reconstruction of different buildings and structures by use of typical network diagrams, which are prepared in advance, created not by classical network analysis methods but by an original construction technology network diagram method. The typical network diagrams can be modified according to the spatial conditions of a certain building and to the amount of construction works and materials. Thanks to the database of data about construction processes and to the typical network diagrams the model of the building process including the cost assessment can be made about 50 times quicker than by use of current cost estimation or project management systems. This method has the possibility to simultaneously create and update quality assurance checklists, environmental plans and safety and health plans in direct linkage to network diagrams, programmes and time schedules as an integral part of the construction technology design. [27]

CONTEC enables to input and retrieve data and specification resulting from various constructional and technological conditions of the construction process, predominantly from bill of quantities produced by designer or by consultants of investor, from the budget or eventually from calculations or invoices in ideal state in automatized manor [30].

Considering above mentioned inbuilt features of the software, utilization of the BIM and especially BI BIM models as a base source of the data for the CONTEC expert systems appears as a very effective way of automatized data retrieval and furthermore automatized creation of the nD models.

5.3 Interlinking BIM model with the CONTEC expert system

As mentioned above, the BIM model in principle is a database of information which can be utilized or interlinked with other databases or software to be developed, or to serve as a base of information used for various task. To create nD models via CONTEC expert system, data from BIM has to be transferred to the CONTEC in order to be processed. Processed data can either be handled as a discrete models nD or via reverse upload may create integrated nD models.

This process must be performed repetitively on demand of the users, especially in the cases when the model data have changed either due to the modification of the model or simply due to the fact that BIM model is developing through the design process into the higher level of detail. Typical application of this process would be an evaluation of the project from the perspective of the investment cost and maintenance cost [27] , health and safety [34], quality etc. in different stages of development such as during zoning permit, building permit or execution phase.

This approach may provide quick feedback to the project time regarding the correctness of the design and verification of decisions based on this information.

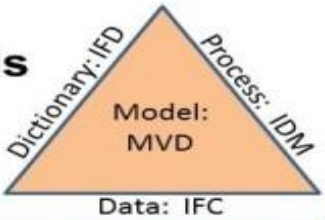
In order to achieve all above mentioned, either common coding interface has to be used, or coding interlink has to be created. As stated in the introduction, coding systems are undergoing fast development and they are very often country specific, or even company specific. This thesis addresses two approaches, where in the first approach root coding system of CONTEC is used in the BI BIM model and second where general BI BIM coding is used and interlink in between CONTEC and BI BIM is defined and set for the automatized data transfer.

5.3.1 On the means of data interchange between BIM and CONTEC

BIM as a database contains data which are bond to every item such as volume, area, type, material etc. hence data organization differs slightly in between various design software but IFC (Industry Foundation classes) as a standard is now widely accepted and defined by ISO (Figure 11) and maintained by independent organisation.

Technical Principles: Basic Standards

There are five basic methodology standards



What it does	Name	Standard
Describes Processes	IDM Information Delivery Manual	ISO 29481-1 ISO 29481-2
Transports information / Data	IFC Industry Foundation Class	ISO 16739
Change Coordination	BCF BIM Collaboration Format	buildingSMART BCF
Mapping of Terms	IFD International Framework for Dictionaries	ISO 12006-3 buildingSMART Data Dictionary
Translates processes into technical requirements	MVD Model View Definitions	buildingSMART MVD

© 2014 buildingSMART

Figure 11 ISO definition base of IFC

ISO 16739:2013 specifies a conceptual data schema and an exchange file format for Building Information Model (BIM) data. The standard exchange file format for exchanging and sharing data according to the conceptual schema is using the clear text encoding of the exchange structure, consists of the data scheme, scheme of specification and reference data, represented as definitions of property and quantity names and descriptions. [2]

For the success full data transfer in between BIM and CONTEC with respect of all above mentioned following criteria must be met.

1) Every item must have a classification code
2) Item carries spatial information such as volume, area, count etc.
3) Data conformity of a model is kept (Same items have same classification codes and properties descriptions)

4) Item has a description in Item Name, Class or Family to enable verification for data conformity of classification and description
5) The unique measure unit has to be defined to every item.
6) Items in the model are created with respect to the means of technological design i.e. implementation of the building.

7) Works or items missing in the model must be known to the person performing the data transfer

Providing that above-mentioned criteria are met; two principles of data transfer can be applied based on the decision process shown on(Figure 12). For the purpose of this thesis two approaches were preselected for the testing of the concept.

1) Application of the modified TSKP (CONTEC) coding directly into the BIM model.
2) Utilization of locally developed general coding SNIM system (SNIM Attachment 2) as a base for automated data transfer.

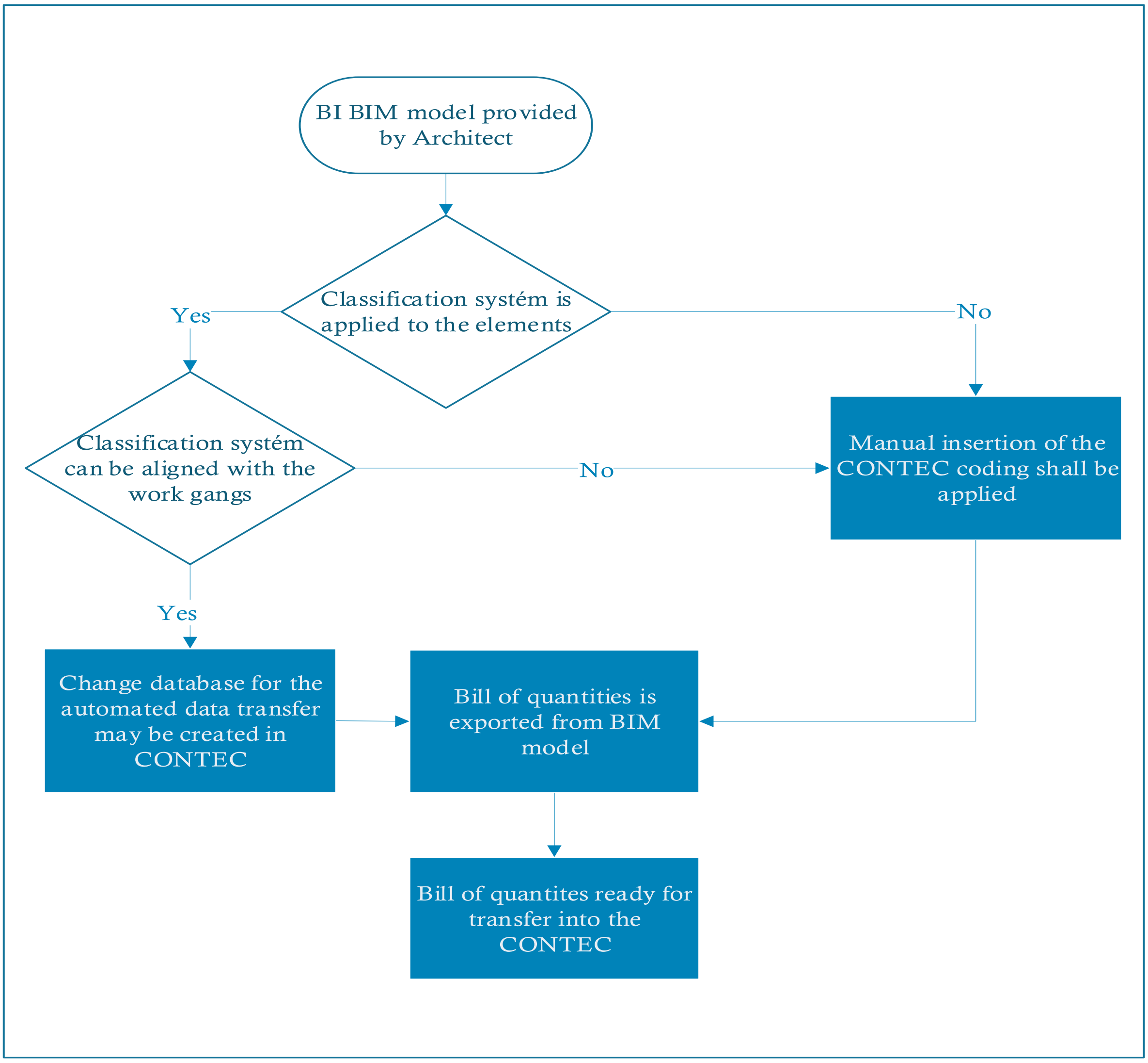


Figure 12 Decision process of manual vs. automated classification

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

Assuming that designers, creating the model do not usually have a knowledge of the construction technology modelling or estimating processes, direct application of coding into the model by a specialist familiar with the issue proved to be the effective approach.

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

Advantages of direct application of the coding into the model, especially in the early stages of the model development is the accurate allocation of the structures/works in - concrete technological stages as well as manual control of model conformity and integrity of a BI BIM model. During the further development of the model, coding can be added for the newly designed items, or inherited [41] for the newly designed, yet existing items. Furthermore, libraries [42] may be created derived from existing projects for the further utilization by a design or development companies.

For the purpose 4-digit basic coding derived from TSKP was applied in bellow case study into the model by means of creation of shared parameters (Attachment nr. 1). in the early phase of the zoning permit and then regularly updated during the design process. CONTEC coding system is based on database of activities and work gangs on site in concrete technological stages.

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

Classification was applied to Families [41] where possible and as a such were inherited during the design process such (typically for piping, equipment, masonry etc.). Eventually they were applied to the individual items or group of items where for example position or type of the item where defining technological process such as in case of hydro-insulation of substructure or hydro-insulation of a roof or in case substructure and above ground structure of concrete.

During the process of the code application various properties may be utilized based on the LOD [43] to filter and group various items based on their special presence in the model or material specification.

Process of the direct application of the coding system into the BIM proves to be best suited for the BIM models with no applied classification system, especially those in low LOD, meaning in early stages of development such as zoning permit or building permit.

Coding was performed by two basic methods, either by Creation of shared parameters (Attachment 1) or by 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 13).

Typ	Klíč	Zkratka	Název činnosti	Množství	M.j.
patka	2701	ZAKL1	ZÁKLADY	41,61	m3
3000x2800x150x45st	2701	ZAKL1	ZÁKLADY	3,75	m3
7900x7500x1200x45st 2	2701	ZAKL1	ZÁKLADY	48,36	m3
Pilota 630	2201	PILO1	PILOTY	35,49	m
Pilota 900	2201	PILO1	PILOTY	188,9	m
Pilota 1200	2201	PILO1	PILOTY	222,14	m
Podlahy 3	4303	SCHO3	SCHODIŠTĚ	7,78	m3
Rameno 2 A 2pp	4303	SCHO3	SCHODIŠTĚ	8,52	m3
Schodistě B nástup rameno	4303	SCHO3	SCHODIŠTĚ	7,08	m3
Schodiště B výstupní ramena	4303	SCHO3	SCHODIŠTĚ	7,27	m3
900x350_hl2700x2200x100 2	3302	SLOU2	SLOUPY SPODNÍ STAVBY	12,61	m3
Betonový sloup D 500mm	3303	SLOU3	SLOUPY A PILÍŘE	113,31	m3
Betonový sloup D 550mm	3303	SLOU3	SLOUPY A PILÍŘE	62,4	m3
V_sloup_kruh	3303	SLOU3	SLOUPY A PILÍŘE	21,52	m3
ŽB Sloup 350x900	3302	SLOU2	SLOUPY SPODNÍ STAVBY	50,32	m3
ŽB Sloup 350x1200	3302	SLOU2	SLOUPY SPODNÍ STAVBY	2,18	m3
ŽB Sloup 595x900	3302	SLOU2	SLOUPY SPODNÍ STAVBY	1,39	m3
ŽB Sloup 1520X350	3303	SLOU3	SLOUPY A PILÍŘE	2,21	m3
RAMPA 1PP-2PP	4103	STRO3	STROPY	335,55	m2
Rampa gastro	4103	STRO3	STROPY	11,96	m2
ŽB DESKA 50	4103	STRO3	STROPY	75	m2
ŽB DESKA 100	4103	STRO3	STROPY	7	m2
ŽB DESKA 100 - hlavice pod deskou	4103	STRO3	STROPY	913,51	m2
ŽB DESKA 150	4103	STRO3	STROPY	38,17	m2
ŽB DESKA 180	4103	STRO3	STROPY	52,87	m2
ŽB DESKA 200	4103	STRO3	STROPY	39,97	m2
ŽB DESKA 245	4103	STRO3	STROPY	53,21	m2
ŽB DESKA 250	4103	STRO3	STROPY	1551,32	m2
ŽB DESKA 250	4103	STRO3	STROPY	17596,87	m2

Figure 13 Sample of manual classification coding

Manual application of classification was performed via excel sheet and by reverse upload applied via design software to the BI BIM, although this did not prove effective due to the fact, that design models are nowadays not ready for construction technology modelling yet, and their division into the logical complexes does not follow technological principles of construction technology modelling 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 to 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 such as shafts, or substructure exterior walls had to be divided and assigned to respective floor, to enable proper construction technology modelling.

Manual coding procedure proved that BIM models are designed in that manner that does not follow technological processes of impletation of the building and automated processing of the data shall either ensure proper set up of a model by the designer, and therefore this approach is suitable for projects where BIM models are not developed with respect to the construction technology design principles.

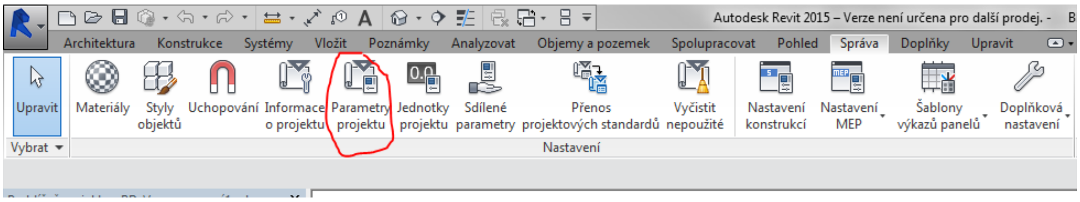
Manual coding seems to be applicable at the cases where no or insufficient classification system was applied.

Further development of the utilization of the TSKP/CONTEC coding in the BIM design process, is that design libraries, derived from the project where above mentioned coding was applied may be used as a base for the further design if desired by investor. This may lead to automated transfer of the date from a BI 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.

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. Measured workload was 15 men/hours including the data processing in the CONTEC and therefore was comparable with the workload necessary for the traditional schedule creation, which is implicitly not based on calculation of volumes of production, time standard, number of workers etc, but rather on estimations, assumptions and experience. Therefore, traditional scheduling is not as accurate and rather dependant on the experience and approach of individual creating the schedule. Along with schedule, resource plan, OHS risk register and plan, and quality assurance plan were automatically created, results in measurable savings in planning processes.

5.3.2.1 Manual coding process

Manual application of the coding into the model is hereby presented on the case of software Revit as it apart from application of Uniclass or Omniclass which are native classification systems of the software open to default classification, which has to be done semi-manually. Below there is a quick description of the process, which in detail is described in Attachment nr. 1. Property for labelling was utilized in our case and parameters were modified using the *Project parameters* function, which can be found on *Administration* tab.



In the following dialog, *Add* has to be selected. The user then will get to the settings of the created parameter, i.e. its properties. For his needs, he sets its type as a shared parameter, which ensures that its functionality is not limited. Parameter than can be reported or exported without problems. The name, discipline, and parameter type are stored in a text file for shared parameters. Name is a default, discipline shall be common, and the type shall be text, parameter shall be set as data. Next, one needs to set the parameter data, primarily to be Instance. In the Category column, select All. This will ensure the ability to mark everything (Figure 14).

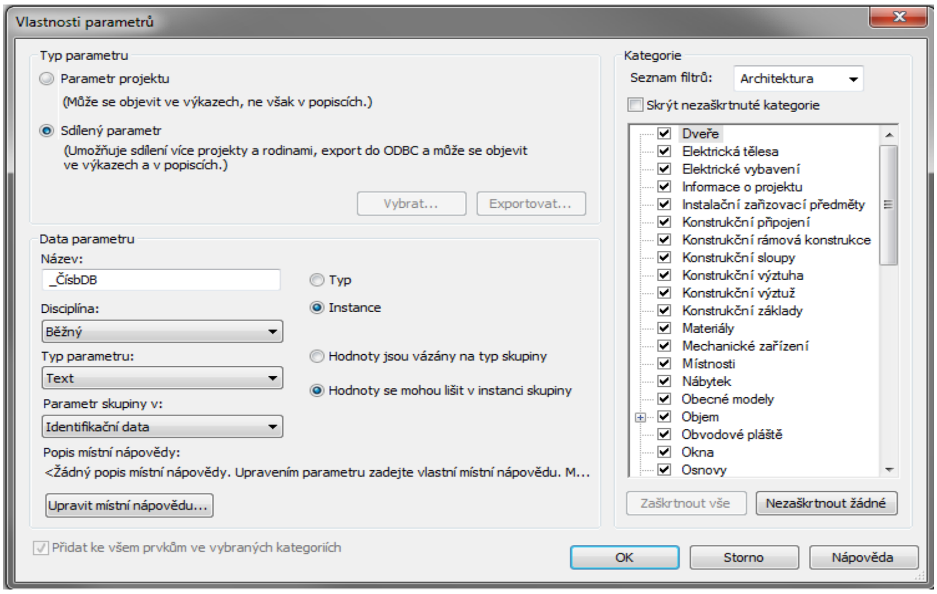


Figure 14 Creating shared parameters

5.3.2.2 Creation of bill of quantities

To create a bill of quantities that in the form of .xlsx the tool *Report* in Revit was used. This tool allows easy to report individual categories of model elements (*statement/Quantity*) as well as can generate *material reports*. It can be found on the toolbar *View* tab, under *create (*Figure 15*)*. Bill of quantities may be exported as a separate table by category or as a single table. This process may be automatised by preparing suitable tables already in the Revit template.

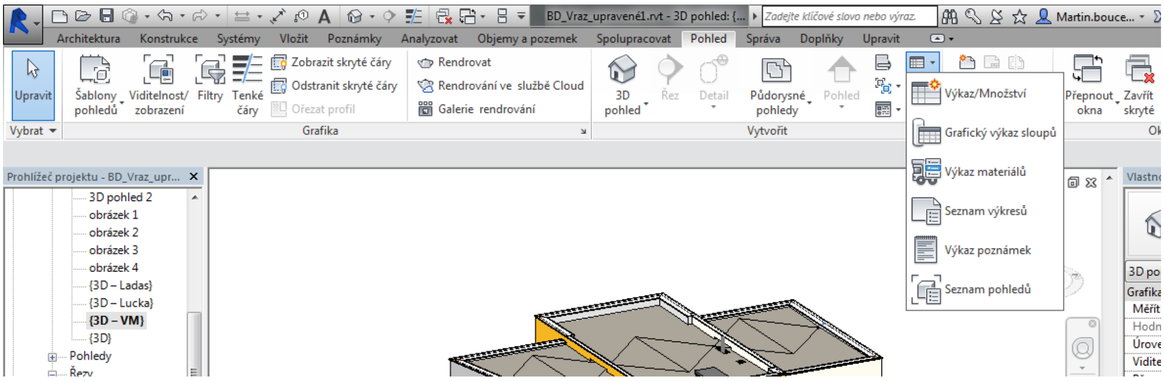


Figure 15 Bill of quantity export

One of the options is to create a *multi-category* report, or a multicategories statement. With this feature, report may be created without looking at the feature of the category. In this way all the necessary data may be exported into a single comprehensive table. This must be followed by filters or grouping functions.

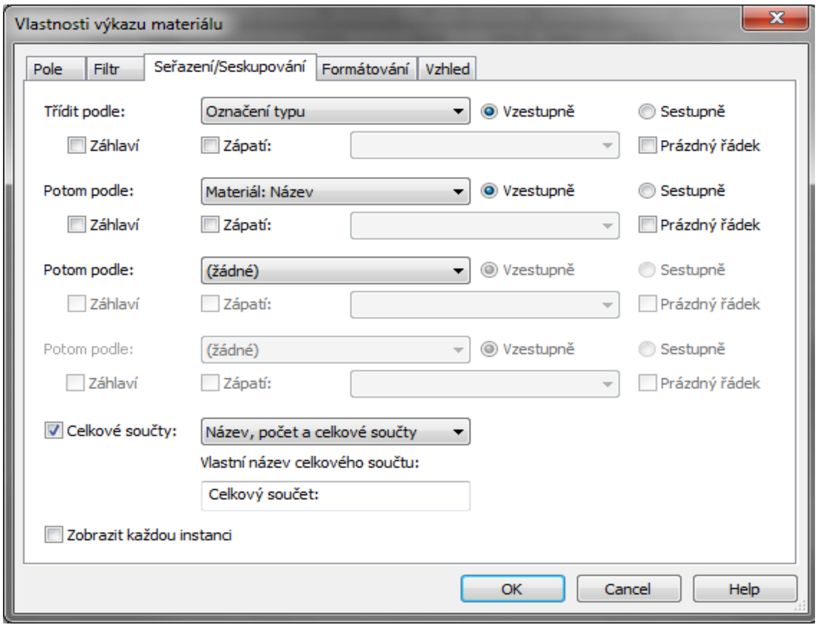


Figure 16 Setting up of the export

This will help to show that each identical element in the report is only one line, but it is necessary to set up the calculation of totals for all fields that give us a quantity for example. Number, volume, area, etc. (Figure 17).

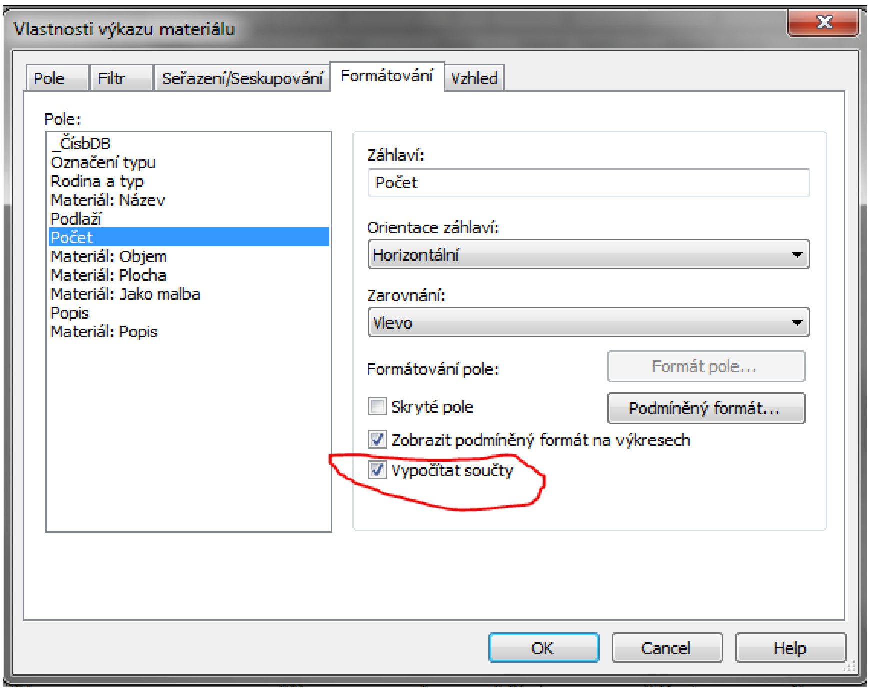


Figure 17 Export properties

To get the final form of the table suitable for export, it is necessary to finally number the individual items. This may be executed in the already grouped form and with the utilization of other tables. Since all the data are still in the model, means that if one parameter is filled in a specific location, its value will be reflected in all others, whether it's plan views, slices, 3D views, or just reports.

This approach is applicable in the case where no classification or unsuitable classification system was applied.

Despite the fact, that this work might be tedious, applied classification may be reused on the new project by means of exporting already defined families as a base of future design works.

5.3.2.3 Import to CONTEC

To upload data from the generated bill of quantities, *transfer foreign budgets* in the CONTEC was used. It is important that the file contains individual item numbering, description, assessment, and unit of measure. It could still contain information about the price, the type of item or the technological stage (Figure 18).

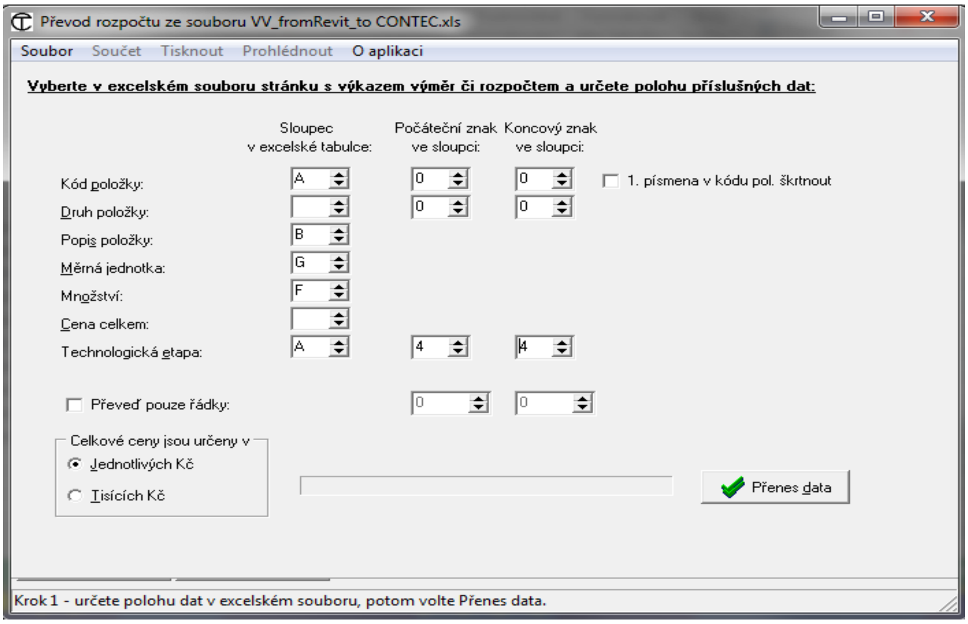


Figure 18 Linking bill of quantities to the CONTEC

After setting up of the data transfer, each item is converted and uploaded. In the first dialog it is possible to discard irrelevant data that could be transferred, e.g. Headers, subtotals, and so on. As explained above, the number of the technology stage information we used already contains in the fourth digit of the item code. This was set during the conversion.

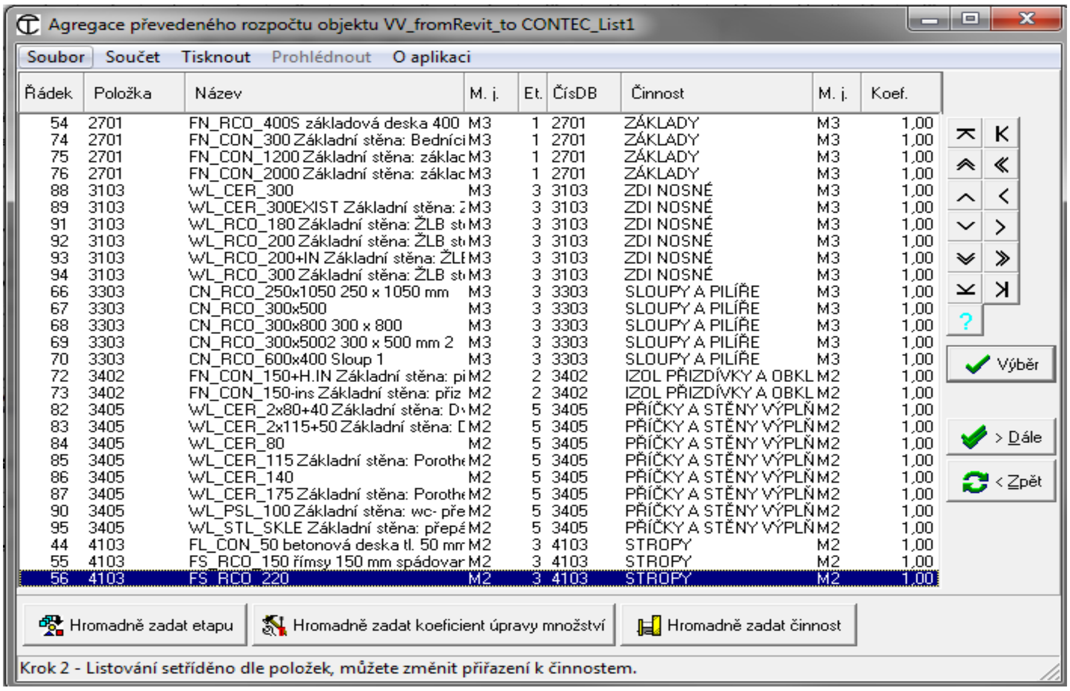


Figure 19 Data transfer into the CONTEC

The above dialog box (Figure 19) shows the data aggregation, where in each row the direct link in between the particular bill of quantity item and CONTEC activities is visible. In the case of manual classification method of the BIM models, the aligning process should work automatically, as it is one of the features of the software. Successful transfer is visually confirmed by visual underlining by a cyan colour or eventually by a yellow colour in the case were assignment of the task shall be verified. Furthermore, conversion factor (Koef.) has to be verified in the case where units of the bill of quantities and CONTEC tasks does not match.

In the next step, quantity adjustment factor can be edited again and then the conversion process is finished and saved in the aggregation *.r file format.

Where possible the best practice would be the adjustment of the export tables directly in Revit, since majority of the BIM items carry all information needed for the calculation of the volume, surface or count to match the desired measurement unit in the transfer bill of quantities to the work gang measurement unit used in CONTEC.

5.4 Case study manual classification of existing model

Manual application of classification system was applied on the project of the office building called FIVE and implemented in Prague by Skanska. Project FIVE was one of the first implementation of the BIM design in the Czech Republic and for this reason no classification system was applied to the BIM model at the first place. Furthermore, due to the complexity of the building and the quality of the information included especially in the HVAC 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 modelled in the BIM and for that reason it was not a subject of the data transfer in between BIM and CONTEC.

Project FIVE(Figure 20) is office building with two underground floors and seven above ground floors with the 20 000 m2 of the gross floor area and as a such represents the typical size of the office building project executed in Prague.

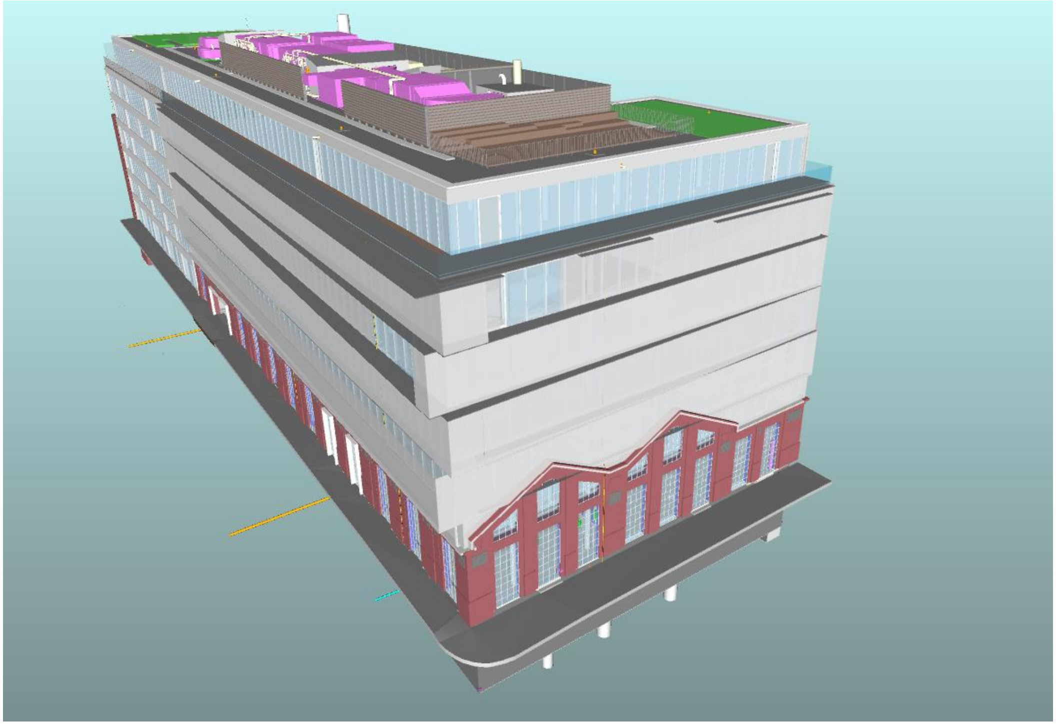


Figure 20 Office building FIVE BIM model

Project FIVE had complete BI 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 21).

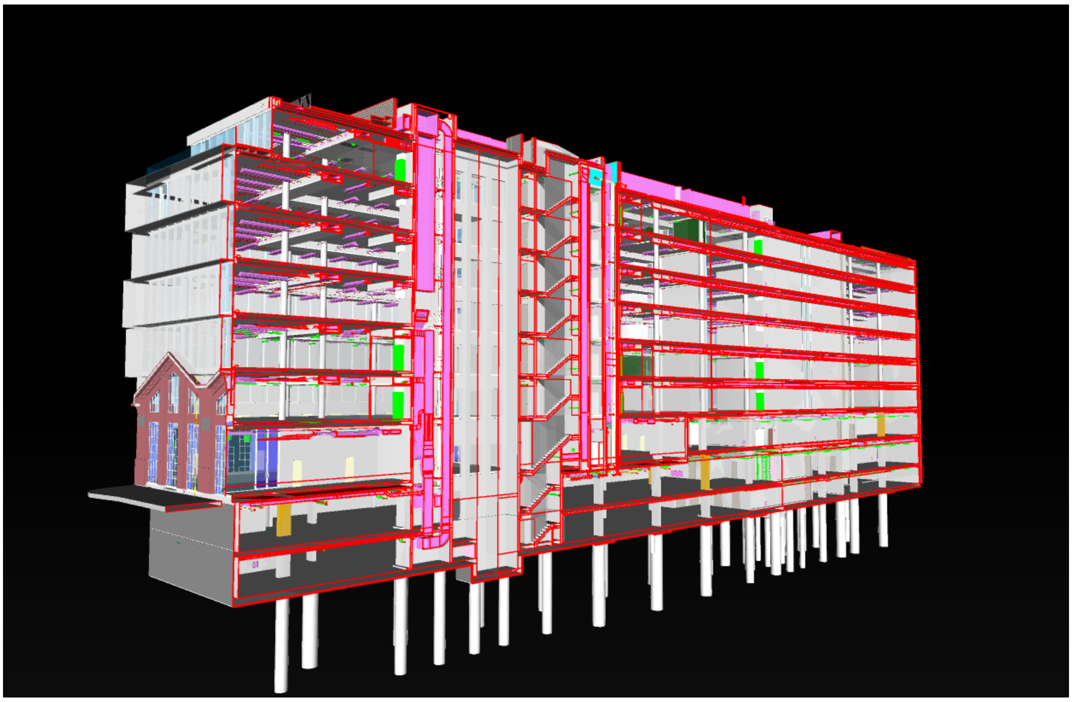


Figure 21 3D section of the building FIVE

Classification system was applied manually in the software Revit by the method of shared parameters briefly described in the text above and Attachment nr. 1.

Report tables for the transfer bill of quantities were set up and reports were created in the form of .xlsx files (Figure 3).

Coding was performed on structures and architectural part only, none of the models of the HVAC, MEP were designed at the time of the test. CONTEC enables construction technology modelling even with incomplete data based on the type of the structure and volume of the structure. Utilizing transferred data to verify and to precise the technological model of the building.

The basic document of the construction technology model is the technological analysis (Figure 22) developed from the combination of the information from the BIM model and data preselected technological model based on type of the building. Where items transformed from the exported bill of quantities are visible for example at the case of process nr. 1402 – items written in small letters, on the contrary processes written in CAPITAL letters without breakdown were calculated from the type network diagram.

CONTEC - Technological analysis of project: 0ADM000A Administrative building — Page: 1

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				

Figure 22 Technological analysis

Schedule and line of balance (Figure 23) was created based on the data, representing 4D of the original BIM model. Based on the 4D model construction duration was 18 months, in compare to the actual construction time of the project representing 19,5 months.

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

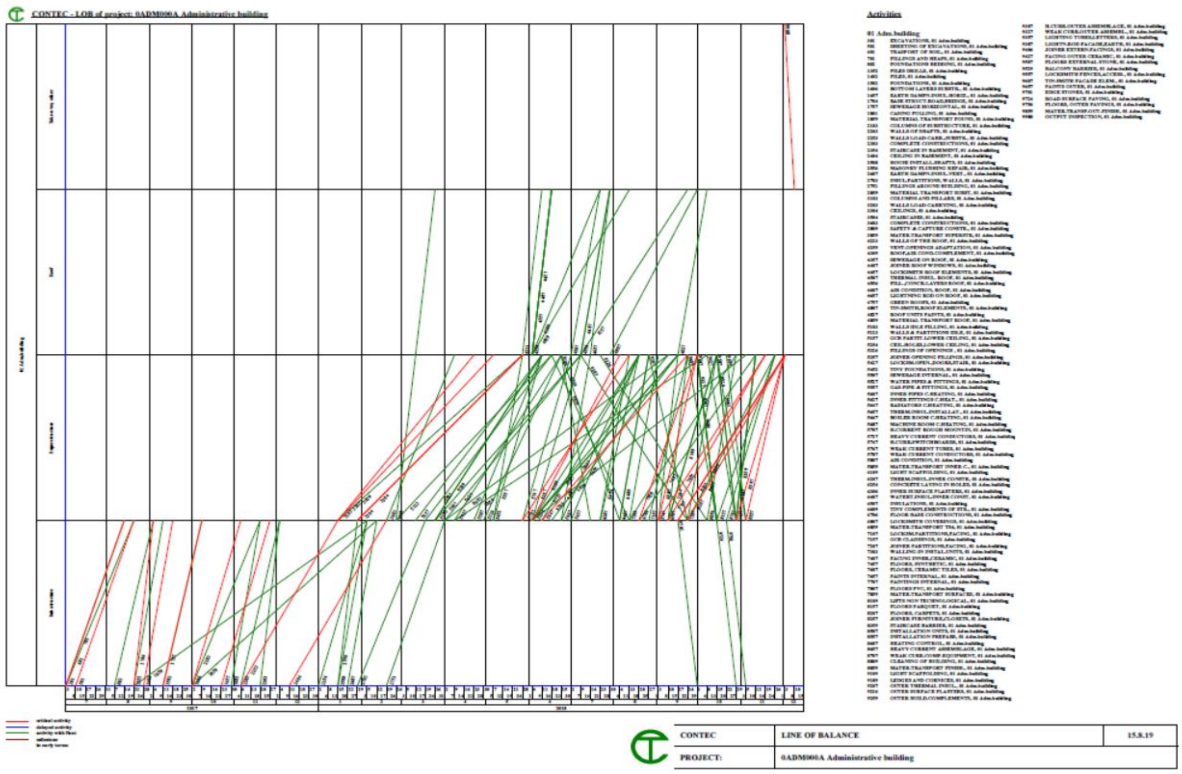


Figure 23 Line of balance of project FIVE(see attachment for the detail)

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

5D model was created by automated pricing of the model, based on the integral CONTEC database creating 5D model (financial data) including its distribution in the time (Figure 24). This chart provides extremely important information especially for the investors when securing the financing of the project.

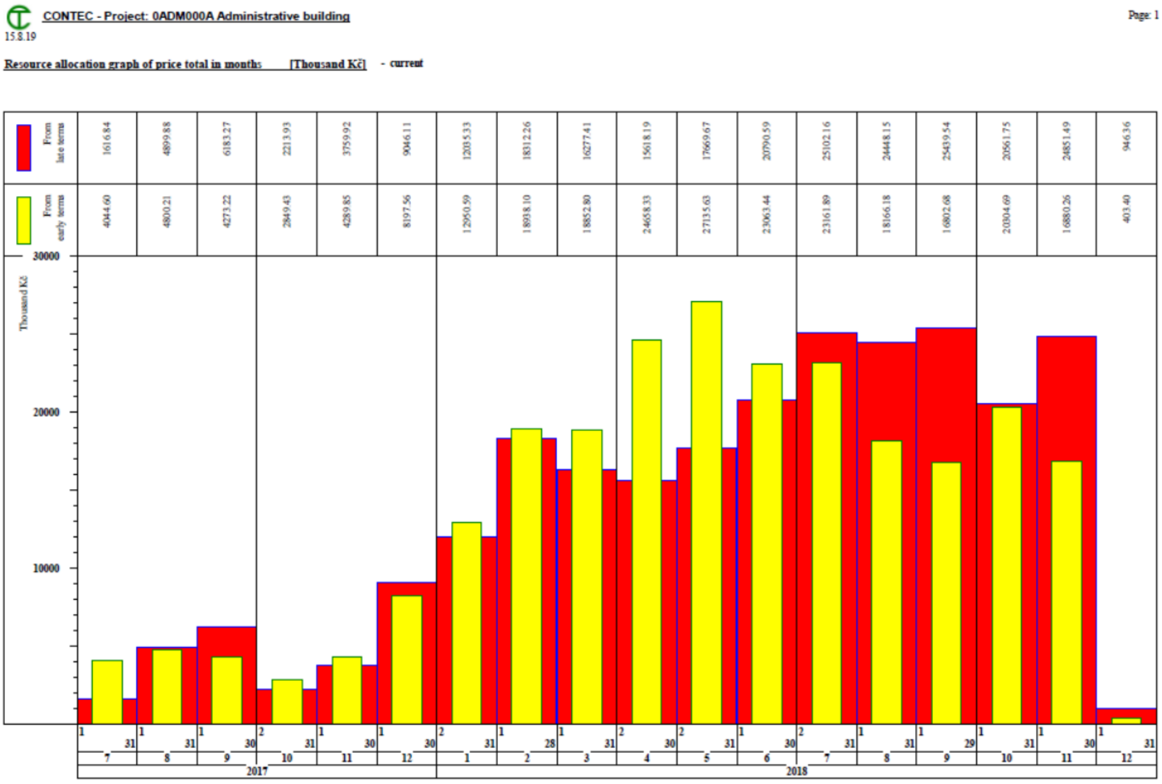


Figure 24 Allocation of financial resources in time

Apart from the financial data, other resources such a human resource was created in form of Graph of number of people in time. Maximum number of workers and distribution of the workers calculated in the resource graph(Figure 25) with the maximum of 106 people correspond to the actual maximal amount of workers which did note exceeded 115 during the construction period.

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

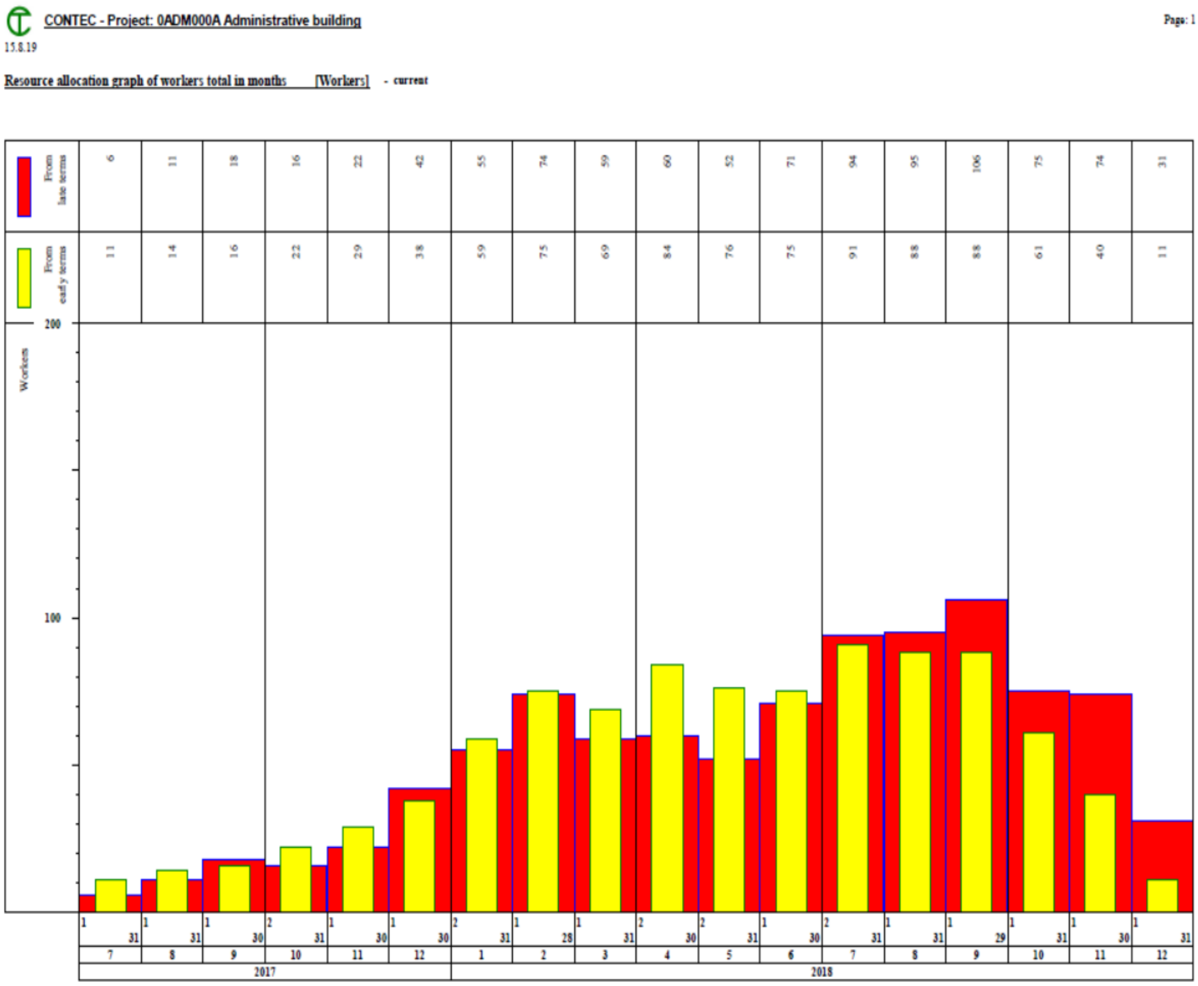


Figure 25 Resource graph - people

Models of the higher order nD were than represented by health and safety plan, plan of Quality assurance see Attachment nr. 2 for the details.

5.4.1 Summary of the case study FIVE results

Manual application of the classification system into the existing model is a time demanding and tedious work, but the only effective solution in the cases when no classification system was applied into the model, or data inconsistency is high, or existing data may not be interlinked to the database. Data transformation from the BIM model into the CONTEC had to be executed with several iterations to properly set up export tables in the Revit.

After successful set up of the export measure units were aligned, and because CONTEC classification was used, the database alignment was done automatically through transfer of the bill of quantities process.

Creation of the discrete nD models from the exported BIM data was than processed through construction technology modelling in CONTEC with acceptable results, despite the fact, that BIM model was not fully coded i.e. technological part of the model was not transferred into the CONTEC.

This single feature of the possibility of construction technology modelling using incomplete data from the model (aligned to the respective part of pre-set technological model) opens great opportunities of the evaluation of the projects and construction technology 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 development and implementation of classification in the small companies or developing markets.

5.5 Automatic linking with existing coding systems

Second applied method was automated linking of the CONTEC database from the existing classification system.

As shown on decision process (Figure 12) data in the BI BIM model have to be evaluated for the feasibility of the automated linking of the classification system to the CONTEC before the linking process begins.

In the bellow case study of the Gemma apartment building SNIM classification system was used for the purpose of testing of automated data transfer in between BIM and CONTEC.

Following key features of the data has to be put into consideration in order to evaluate feasibility of transformation (Figure 26).

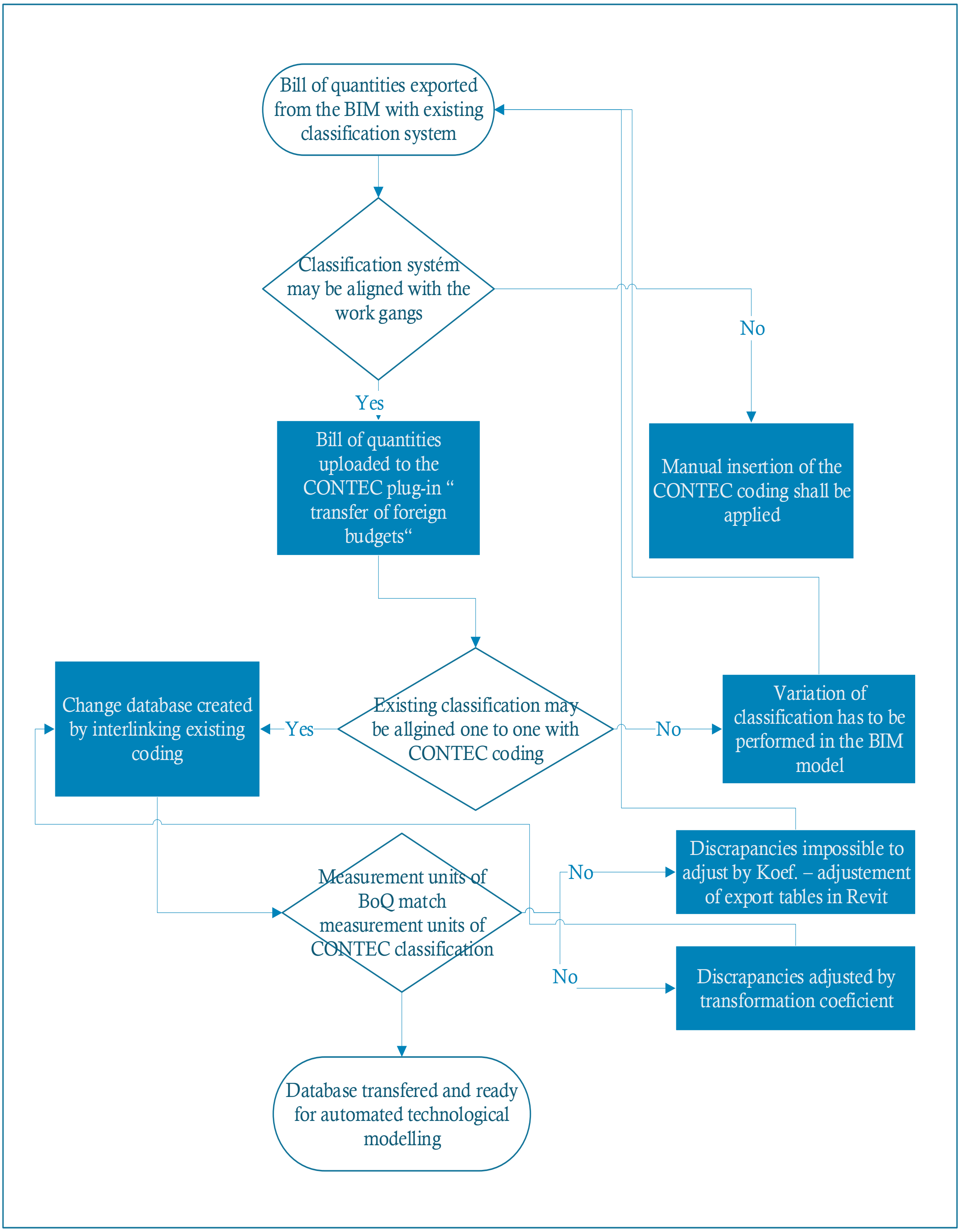


Figure 26 Creation of change database creation for automated transfer of BIM data into the CONTEC

1) Existing classification system applied in the model is based on the division of labour i.e. works can be differentiated in between technological stages (TE)

   Example: Insulation of underground structures vs. Insulation of Roof

   or

   Foundation slab vs. Ceiling slab

2) Existing classification system has sufficient level of detail – must not aggregate works from different work stages under one code

   Example: SNIM System aggregates complete flooring layer composition under one code – base layer of floor is executed in TE 6, Floor surface TE 7

3) Measure units of existing classification system correspond to the classification system of CONTEC

Shall one more of above mentioned conditions be not met, adjustments of either bill of quantities, BIM model or existing classification system must be performed in order to ensure repetitive faultless data transfer in between BIM and CONTEC.

Following measure were applied in individual cases:

In the case nr. 1 and 2 – two approaches may be applied:

A) individual items of the bill of quantities may be aligned with proper code of CONTEC classification individually based on description of the individual item
B) Existing classification system may be adjusted in the BIM model to enable reflection of technological stages (TE)

Approach (A) is applicable and effective in the cases when transfer is required for individual project only or when limited number of items are problematic in the transfer. Approach is not effective when repeated transfers are needed or when classification system is impossible to modify.

In the case nr. 3 two approaches may be applied:

A) Transformation coefficient Koef. may be adjusted in the transformation database for individual items or even for linked classification codes. Information is stored in the change database and reused during every transfer. The transformation coefficient Koef. is used to calculate the difference in between the measure unit of the bill of quantities and measure units of the CONTEC activity.

   Example:
   3103 ZDIP Bearing walls *measurement unit m3*

   vs. export bill of quantities

   3103 Concrete wall thickness 0,25m *measurement unit m2*

   Koef = 0,25

B) Export tables of the BIM model in the Revit may be adjusted in order to match required measurement units.

Both approaches are equally effective, yet approach (B) is more beneficial for the future reuse of the BIM libraries and export tables.

After the alignment of the classification systems and measurement units, change database is created and transformation may be repeated using the BIM data from the respective BIM model as well as from any default BIM model utilizing same classification system for which the change database was created.

5.1 Case study automated transfer of BIM data

Automated data transfer was tested on the project Gemma. Project Gemma is a apartment house consisting of 59 apartments and retail units (Figure 27). It is constructed in the open pit with two underground and 5 above ground floors with the pile foundation. Gemma is situated in Prague and is currently under construction. Project is designed in BIM with the application of the SNIM

Figure 27 Gemma apartment building

classification system. It is a most recent project with the application of this coding and most probably first project currently under construction. Project was designed by company Helika who is the one of the main developers of this system.

Figure 28 Section of Gemma in BIM model

BIM model of execution documentation was used for the purpose of this thesis in order to export the necessary data from the model. The export was performed through one general table consisting of not only structural and architectural model including foundation piles but also model of heating, cooling, sprinkler systems, as well as cable trays of high current. Items of earth works, external infrastructure, low current and utility connections were not included in the model. Model did not include heat source as central heat exchanger was not part of the building.

Transferable model data were exported in the form of .xlsx table which was processed by a method described above. Exchange database was created for the SNIM classification system applied to the model.

Due to the limitations of SNIM described above, original SNIM coding had to be adjusted in order to fit requirements of automated transfer, especially in the following cases.

Compositions of the floors and roofs are according to the SNIM definition bearing one classification code for the complete composition. These were examples where original classification system had to be modified by adding extra letter or number defining the technological stage. Due to the fairly open manor of the classification, this is possible without violating basic rules of the SNIM system. SNIM system is open in definition and shall be set up individually for every project. Yet in order to maintain automation in nD modelling processes, definition shall be kept containing the upgraded definitions, especially I the roof and floors compositions.

The SNIM classification system is still rather underdeveloped in the technological models such as water, sewage, heating etc. and for that reason these items could have been transferred only partially. Further development of the classification of the technological part shall be subject of the further development in order to achieve detailed work with the data. For example, is current classification system unable to reflect difference between the main distribution lines and final elements. On the contrary completing elements are well distinguished.

Generally data used for the automated transformation were more detailed, hence the automatically generated nD models are more accurate as a result.

Providing 4D time schedule (Figure 29)

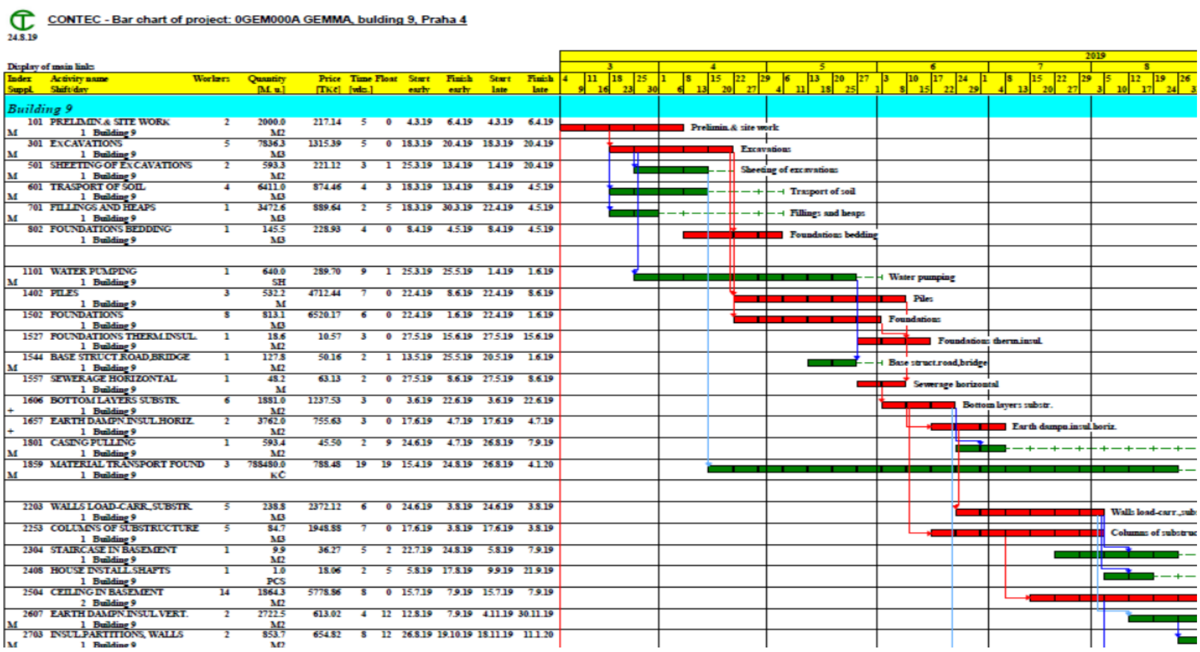


Figure 29 Generated time schedule Gemma

5D model represented by requirements of financing for respective months of the construction period (Figure 31) developed from automatically calculated budget (bill of quantities priced using internal price database).

CONTEC - Bill of quantities of building: 0GEM000A Building 9 Page: 4

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MAIN BUILDING PRODUCTION

Seq. number	Item	Index from ND	N a m e	M. u.	Quantity [M. u.]	Unit price [Kč/m. u.]	Price total [thousand Kč]	Supplier
GROUP OF BUILDING PARTS 1 - EARTHWORKS								
1	1100	101	PRELIMIN.& SITE WORK	M2	2000.00	108.60	217.14	M
2	1101	1101	WATER PUMPING	SH	640.00	452.70	289.70	M
3	1300	301	EXCAVATIONS	M3	7836.27	167.90	1315.39	M
4	1500	501	SHEETING OF EXCAVATIONS	M2	593.33	372.70	221.12	M
5	1501	1801	CASING PULLING	M2	593.43	76.70	45.50	M
6	1600	601	TRASPORT OF SOIL	M3	6410.98	136.40	874.46	M
7	1700	701	FILLINGS AND HEAPS	M3	3472.55	256.20	889.64	M
GROUP OF BUILDING PARTS 1 - EARTHWORKS TOTAL							3852.95	
GROUP OF BUILDING PARTS 2 - FOUNDATIONS								
8	2201	1402	PILES	M	532.18	8855.00	4712.44	
9	2700	802	FOUNDATIONS BEDDING	M3	145.54	1573.00	228.93	
10	2701	1502	FOUNDATIONS	M3	813.09	8019.00	6520.17	
GROUP OF BUILDING PARTS 2 - FOUNDATIONS TOTAL							11461.54	

Figure 30 Budget based on transferred data

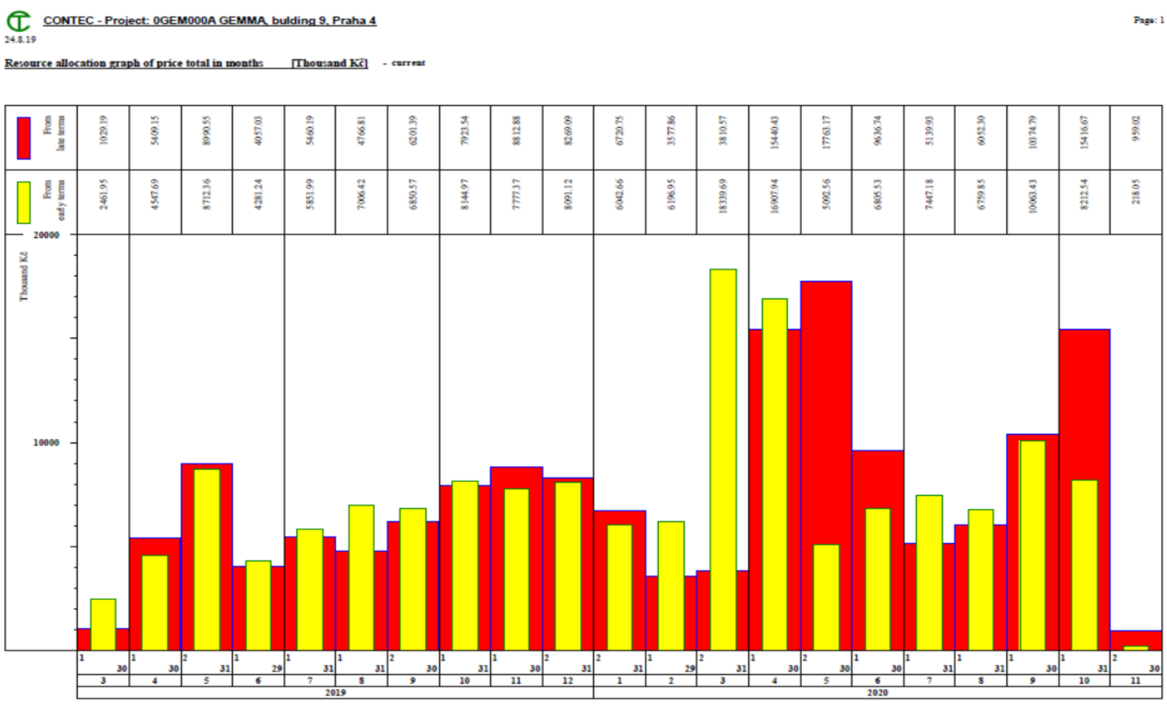

Figure 31 Requirements of financing in time Gemma

The nD models are then represented 6D human resource plan (Figure 32).

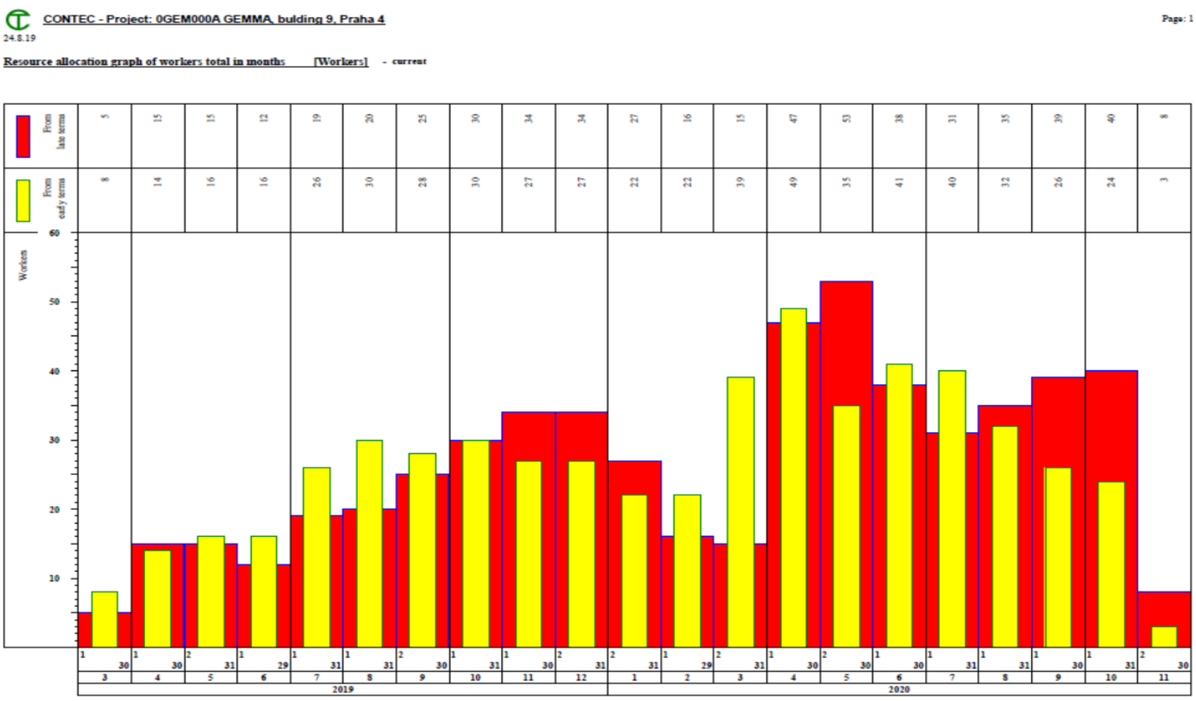

Figure 32 Human resource plan

7D quality assurance and testing plan – KZP(Figure 33) including the quality control schedule (Figure 34).

CONTEC - Quality assurance checklist of project: 0GEM000A GEMMA, bulding 9, Praha 4 — Page: 1
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Index Number	Activity name	Supplier	Subject of check	Performed by MBP Spec.	SBP Test.	Way Proof	Performing check acc.	Description of check	Term early late
Building 9									
101 1	PRELIMIN.& SITE WORK Building 9 Evaluation of check:	M	POLOHOVÉ A VÝŠKOVÉ VYTÝČENÍ OBJEKTU	+ G+		M Zápis ve st.d. Sitemaster's sign./Date:	ČSN ISO 4463;tř.zn. 730411,ČSN 73 0420	Geodetickým měřením Tester's signature/Date:	9.3.19 9.3.19
301 1	EXCAVATIONS Building 9 Evaluation of check:	M	POLOHOVÉ A VÝŠKOVÉ VYTÝČENÍ OBJEKTU	+ G+		M Zápis ve st.d. Sitemaster's sign./Date:	ČSN ISO 4463;tř.zn. 730411,ČSN 73 0420	Geodetickým měřením Tester's signature/Date:	23.3.19 23.3.19
301 1	EXCAVATIONS Building 9 Evaluation of check:	M	KVALITA ZEMNÍCH PRACÍ	+		M Zápis ve st.d. Sitemaster's sign./Date:	Třídicí znak 721017; TNI prEN 16907-5	Měřením shody Tester's signature/Date:	30.3.19 30.3.19
501 2	SHEETING OF EXCAVATIONS Building 9 Evaluation of check:	M	PAŽICÍ A PODPĚRNÉ VÝKOPOVÉ KONSTRUKCE	+ S+		A,Z Záznam o kontr. Sitemaster's sign./Date:	ČSN EN 13331,13377, 14653;zn:738121,2,6	Kontrolní zkoušky, odborné posouzení Tester's signature/Date:	30.3.19 6.4.19
501 1	SHEETING OF EXCAVATIONS Building 9 Evaluation of check:	M	GEOTECHNICKÉ VLASTNOSTI ZEMIN	+ T+	+	A,Z Záznam, zápis Sitemaster's sign./Date:	ČSN EN ISO 22476,..; T.zn:721004,07,11-31	Ter.penetrač.zkoušky laboratorní zkoušky Tester's signature/Date:	30.3.19 6.4.19
601 1	TRASPORT OF SOIL Building 9 Evaluation of check:	M	SILNIČNÍ NAKLADNÍ VOZIDLA	+	+	A,M Zápis ve st.d. Sitemaster's sign./Date:	Třídicí znak:30....	Techn.prohl.vozidel mimo povin.interval Tester's signature/Date:	23.3.19 13.4.19
701	FILLINGS AND HEAPS		SKLÁDKOVÁNÍ ODPADŮ	+		Z	ČSN 83 803.	Dodržení technických	23.3.19

Figure 33 Quality assurance plan KZP

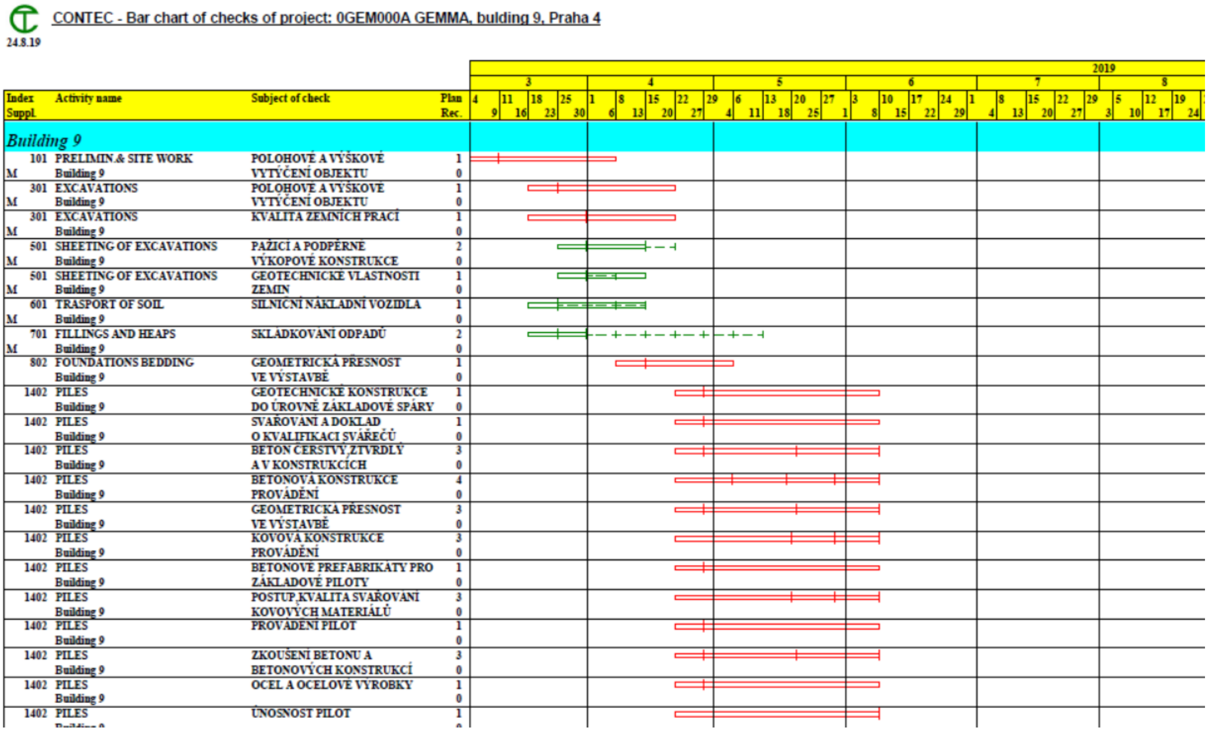


Figure 34 Quality assurance schedule

8D is than represented by environmental risk plan.

CONTEC - Environmentální plán akce: 0GEM000A GEMMA, bulding 9, Praha 4 — Strana: 1

24.8.19

Index Kód EA Počet	Název činnosti Environmentální aspekt (EA)	Upřesnění Polutanty	Dopad na ŽP člověk půda	 vzduch prostř.	 voda jiné	Dodavatel Kontrola Četnost kontroly	 Opatření	Významnost T. možný T. přípustný	Doklad Zařízení Odpovědnost	Četnost Limit m. j.	 Předpis Způsob řízení
Building 9											
101 10 1	PRELIMIN.& SITE WORK Ochrana vod a půdy Úkapy a úniky Zhodnocení kontroly:	Building 9 Úkapy a úniky NCHLAP, ropných látek, aj.	 +		 +	M Záchyt. vany, asanač. pros. 1 x měs. Podpis stavbyved./Datum:	 Opatř. proti vniknutí neb. látek do vody a půdy	17 4.3.19 4.3.19 Podpis kontrolora/Datum:	STP, Hav. plán, B Stavby Stavbyvedoucí		 Zák. 254/01 Sm. 20/02
301 07 1	EXCAVATIONS Ostatní odpad Nakládání se zeminou Zhodnocení kontroly:	Building 9 Zemina	 +		 +	M Zabezpečení před znehodnoc. 1 x měs. Podpis stavbyved./Datum:	 Předcházení vzniku odpadu, opětovné využití	13 18.3.19 18.3.19 Podpis kontrolora/Datum:	Průběžná evidence Stavby Stavbyvedoucí		 Zák.185/01, Vyh.383/01 Sm.20/02
301 14 1	EXCAVATIONS Hluk Požadavky na stroje Zhodnocení kontroly:	Building 9 Hluk způsobený používaným zařízením	 +	 +		M Dodrž. povol. emisí hluku 1 x měs. Podpis stavbyved./Datum:	 Kontrola zař. z hlediska emisí hluku	10 18.3.19 18.3.19 Podpis kontrolora/Datum:	Prohlášení o shodě Stavby Provozovatel		 Nař. vl. 9/02
501 07 1	SHEETING OF EXCAVATIONS Ostatní odpad Nakládání se zeminou Zhodnocení kontroly:	Building 9 Zemina	 +		 +	M Zabezpečení před znehodnoc. 1 x měs. Podpis stavbyved./Datum:	 Předcházení vzniku odpadu, opětovné využití	13 25.3.19 1.4.19 Podpis kontrolora/Datum:	Průběžná evidence Stavby Stavbyvedoucí		 Zák.185/01, Vyh.383/01 Sm.20/02
501 19 1	SHEETING OF EXCAVATIONS Prašnost Ochrana osob Zhodnocení kontroly:	Building 9 Prach vznikající při staveb činnosti	 +	 + +		M Dodržování limitů pro prach 1 x měs. Podpis stavbyved./Datum:	 Použ. osobních ochranných prostř. a protipraš. opatř.	13 25.3.19 1.4.19 Podpis kontrolora/Datum:	 Stavby Stavbyvedoucí	 10.00 mg/m3	 Nař. vl. 178/01
601 07 1	TRASPORT OF SOIL Ostatní odpad Nakládání se zeminou Zhodnocení kontroly:	Building 9 Zemina	 +		 +	M Zabezpečení před znehodnoc. 1 x měs. Podpis stavbyved./Datum:	 Předcházení vzniku odpadu, opětovné využití	13 18.3.19 8.4.19 Podpis kontrolora/Datum:	Průběžná evidence Stavby Stavbyvedoucí		 Zák.185/01, Vyh.383/01 Sm.20/02
701 07 1	FILLINGS AND HEAPS Ostatní odpad Nakládání se zeminou Zhodnocení kontroly:	Building 9 Zemina	 +		 +	M Zabezpečení před znehodnoc. 1 x měs. Podpis stavbyved./Datum:	 Předcházení vzniku odpadu, opětovné využití	13 18.3.19 22.4.19 Podpis kontrolora/Datum:	Průběžná evidence Stavby Stavbyvedoucí		 Zák.185/01, Vyh.383/01 Sm.20/02

Figure 35 Environmental risk register

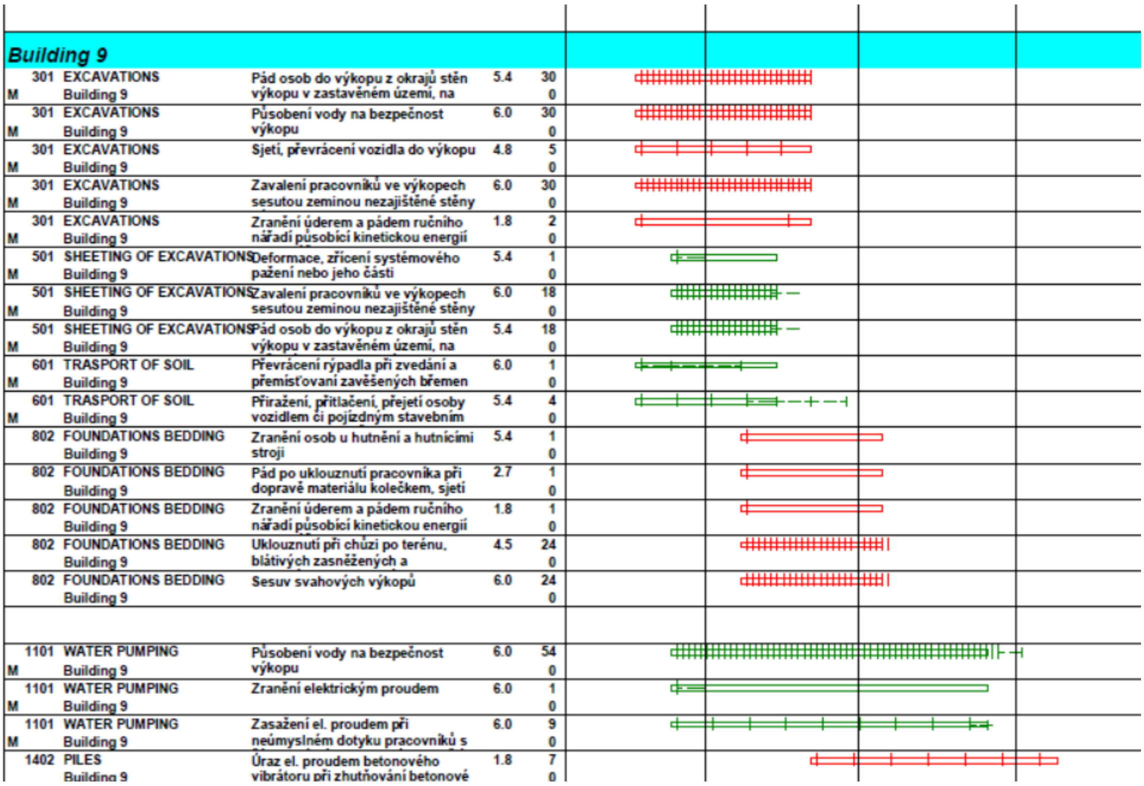
9D is represented by OHS register (Figure 36) and Health and safety plan

CONTEC - Plán BOZP akce: 0GEM000A GEMMA, bulding 9, Praha 4 Strana: 1

24.8.19

Index Kód Počet	Název činnosti	Dodavatel	Název rizika BOZP	Ohrožení	Následky Opatření	HRiz PVN MNO	Odpovědnost Předpis Doklad	Četnost T. možný T. přípustný
Před začátkem								
1 A00160 1	PŘED ZAČÁTKEM STAVBY Před začátkem	REGBOZ	Nahlášení na OIP	Vedení společnosti	Pokuta	0.3 1 1	Stavební společnost Z 309/2006 sb. §15odst1b Potvrzení z OIP	1 x měsíčně 4.3.19 4.3.19
Nahlásit na OIP								
	Zhodnocení kontroly:			Podpis stavbyved./Datum:			Podpis kontrolora/Datum:	
2 A00041 21	VŠECHNY ČINNOSTI Všechny objekty	REGBOZ	Nedostatečné školení BOZP	Pracovníci na stavbě	Pád břemene, nářadí, popáleniny, povrchové zranění, smrt	9.0 3 10	KOOBOZP, Stavbyvedoucí 309/2006 §11/3, §15/2 Školení	1 x měsíčně 4.3.19 4.3.19
Důsledně provádět školení nových pracovníků na staveništi u každého nového nástupu pracovníka, pracovní čety								
	Zhodnocení kontroly:			Podpis stavbyved./Datum:			Podpis kontrolora/Datum:	
2 A00050 535	VŠECHNY ČINNOSTI Všechny objekty	REGBOZ	Propíchnutí, pořezání chodidla např. hřebíky a jinými ostrohrannými částmi, pořezání sklem a pod	Pracovník	Poranění chodidla, řezné rány	4.5 3 5	Pracovník, vedoucí pracovník 591/2006 Školení na pracovišti	1 x denně 4.3.19 4.3.19
Včasné odstraňování vybouraných částí s ostrými hranami, používání OOOP (pracovní obuv s pevnou podrážkou)								
	Zhodnocení kontroly:			Podpis stavbyved./Datum:			Podpis kontrolora/Datum:	
2 A00063	VŠECHNY ČINNOSTI Všechny objekty	REGBOZ	Pád, vyklouznutí nářadí(i části) nebo stavebního materiálu: volně loženého z	Pracovník, pracovníci kolem	Zasažení části těla předmětem, poranění nohy a ruky, tržné rány, otlaky	5.4 3	Pracovník, vedoucí pracovník 101/2005 262a591/2006 258/	kontinuálně 4.3.19

Figure 36 OHS risk register



Building 9					
 M	301	EXCAVATIONS Building 9	Pád osob do výkopu z okrajů stěn výkopu v zastavěném území, na	5.4	30 0
 M	301	EXCAVATIONS Building 9	Působení vody na bezpečnost výkopu	6.0	30 0
 M	301	EXCAVATIONS Building 9	Sjetí, převrácení vozidla do výkopu	4.8	5 0
 M	301	EXCAVATIONS Building 9	Zavalení pracovníků ve výkopech sesutou zeminou nezajištěné stěny	6.0	30 0
 M	301	EXCAVATIONS Building 9	Zranění úderem a pádem ručního nářadí působící kinetickou energií	1.8	2 0
 M	501	SHEETING OF EXCAVATIONS Building 9	Deformace, zřícení systémového pažení nebo jeho části	5.4	1 0
 M	501	SHEETING OF EXCAVATIONS Building 9	Zavalení pracovníků ve výkopech sesutou zeminou nezajištěné stěny	6.0	18 0
 M	501	SHEETING OF EXCAVATIONS Building 9	Pád osob do výkopu z okrajů stěn výkopu v zastavěném území, na	5.4	18 0
 M	601	TRASPORT OF SOIL Building 9	Převrácení rýpadla při zvedání a přemisťovaní zavěšených břemen	6.0	1 0
 M	601	TRASPORT OF SOIL Building 9	Přiražení, přitlačení, přejetí osoby vozidlem či pojízdným stavebním	5.4	4 0
	802	FOUNDATIONS BEDDING Building 9	Zranění osob u hutnění a hutnícími stroji	5.4	1 0
	802	FOUNDATIONS BEDDING Building 9	Pád po uklouznutí pracovníka při dopravě materiálu kolečkem, sjetí	2.7	1 0
	802	FOUNDATIONS BEDDING Building 9	Zranění úderem a pádem ručního nářadí působící kinetickou energií	1.8	1 0
	802	FOUNDATIONS BEDDING Building 9	Uklouznutí při chůzi po terénu, blátivých zasněžených a	4.5	24 0
	802	FOUNDATIONS BEDDING Building 9	Sesuv svahových výkopů	6.0	24 0
 M	1101	WATER PUMPING Building 9	Působení vody na bezpečnost výkopu	6.0	54 0
 M	1101	WATER PUMPING Building 9	Zranění elektrickým proudem	6.0	1 0
 M	1101	WATER PUMPING Building 9	Zasažení el. proudem při neúmyslném dotyku pracovníků s	6.0	9 0
	1402	PILES Building 9	Úraz el. proudem betonového vibrátoru při zhutňování betonové	1.8	7 0

Figure 37 Health and safety plan/schedule

5.1.1 Summary of the case study Gemma results

Automated application of the classification system into the existing model is a feasible solution in the cases where either classification system fulfilling above defined requirements is put in place, or the classification system is open for editing, or based on TSKP. Gemma case proved that automated nD (in this case 9D) model creation is feasible in discrete modelling approach and by reverse transformation of the data into the model potential even in integrated modelling approach.

Gemma case proved that further development of SNIM system is needed, especially in MEP and HVAC part. Furthermore, breakdown of composition layers of floors, roofs and walls has to be performed in order to enable proper pricing and activity alignment. Development of such a classification system would be time demanding and would require investment, but would bring considerable savings, especially for the developer who is performing repetitive project like in case of project Gemma developed by Residential development of Skanska.

In such a case library containing proper classification as well as description shall be developed as well as export tables. Under these circumstances would be the change database reusable and data transfer in between BIM and CONTEC may be performed repetitively in various stages of development of the project and due to the feature of CONTEC enabling calculations based on partial data only enabling even in very early stages.

Lately research had been conducted [21] which may result to applicable classification system for the condition of Czech market, where after creating change database by means described in this thesis fully automated nD model creation may be achieved.

Chapter 6 Summary of achieved results

The following targets of the thesis were achieved:

1) The key target of the thesis was to enable automated nD model creation based on the BIM data not only 4D and 5D but also nD models of 6D Plan of resources, 7D Quality plans 8D Environmental risk plan 9D Health and safety risk plan was achieved by interlinking BIM model to the CONTEC system and by automated creation of the discrete nD models of the original BI BIM model.

2) Existing classification systems were evaluated for the purpose of the automated data transfer and classification system was selected for the testing purposes.

3) Two methods were developed and tested i.e. manual coding and automated transformation to achieve interlink existing BIM data and CONTEC system thus to produce required data.

4) The prerequisites of the BIM model to enable data transfer from the model for the both methods were defined. These prerequisites would be applicable to any transformation of the data, not only to the CONTEC but to general data processing of BIM data.

5) Both methods were applied to the existing projects and compared to the actual construction times or to the contracted construction times in case of Gemma, thus the accuracy of the method was tested.

6) Results of the pilot project are demonstrated in the case studies, proving feasibility of this method and defining conditions of the method accuracy. Automatically created data was compared to the data of existing project either real execution or contracted execution times and requirements.

Chapter 7 Conclusions and expected benefits of the work

Basic integrated BIM model was used for automated creation of 4D, 5D and up to the 9D nD such as for example, 4D and 5D but also 6D Plan of resources, 7D Quality plans 8D Environmental risk plan 9D Health and safety risk plan.

Process of the direct application of the CONTEC classification system into the BIM proves to be best suited for the BIM models with no applied classification system, especially those in low LOD (Level of detail), for use especially in early stages of development such as zoning permit or building permit or in the countries where no classification system of the elements in BIM is not developed or accepted by the industry.

Once applied into the model classification may be developed together with the model or reused simply by application existing families and elements in the new future models.

Limitation of this method is the fact that the designer or creator of the BIM model has to take into consideration the fact, that structures in the model has to be modelled with respect to technological processes of construction and furthermore in the data structure that meets criteria described in this paper.

In the cases where all above mentioned criteria are not met, level of automation of the process, i.e. necessity of data processing before using the CONTEC drops considerably and requires a certain amount of manual work.

Automated transformation of the BIM data proved to be feasible solution in the cases where classification system is already applied into the BIM model and when the applied classification system is possible to align with the work gangs. In the case of tested SNIM system is connectivity achievable when modifications were performed in the SNIM classification. Despite the fact that modification within the given borders of the SNIM system is expected and permitted, for the process of automation it would be necessary that modified classification is kept for the more than one project. This would be beneficial for the big developers where design requirements are set and repetitive. Furthermore, development of the BIM classification developed or based on TSKP would enable at least in the conditions of the Czech Republic much larger connectivity to the existing solutions which are currently present on the market.

1) Main contribution of the thesis to the scientific field

Automated creation of the nD models through CONTEC provides feasible alternative to the methods which are currently being developed such as [17] or [8], but provides wide range of results, not limited to 4D and 5D but as well to the nD models. It defines requirements of future research and definition of classification systems to full fill the requirements of Czech market as well as future requirements of EU.

2) Main contribution to the practical use

Definition of the means of transformation and the automated creation of nD models improves the productivity of the construction management works. Successful solution of this problem enables the early evaluation of constructed buildings with respect to the level of development of a BIM model, providing information about the construction time as well as rough estimation of construction cost in the preparation phase. In the execution phase utilisation of this approach shall create complete set of construction technological design documentation.

3) Main contribution for the educational purposes

Use of advanced technologies such as BIM modelling is rapidly developing within public and private construction projects. The nD model creation is one of the most researched and demanded features that are developed for the future use of BIM. Automated creation of nD models shall become one of the teaching concepts of the BIM as an integral part of process of technological modelling.

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List of figures

List of abbreviations:

BIM – Building information modelling

GUID – Global unique identifier – *unique number assigned to every element of the BIM model*

TSKP – Třídník stavebních konstrukcí a prací – *Czech standard classification system* [23]

LOD – Level of detail – *definition of level of detail to which is BIM model developed.*

TE – Technological stage

IFC – Industry foundation classes [2]

SNIM – Standardizace negrafických částí modelu(*Standardisation of non-graphic elements of the model*) [26]

MEP - Mechanical electrical and plumbing installations

HVAC - Heating ventilation and cooling installations

MBP - Main building production – *Foundation, Bearing structures, walls, facades etc.*

SBP - Secondary building production – *Finishes, MEP, HVAC etc.*

OHS - Operational health and safety