CZECH TECHNICAL UNIVERSITY IN PRAGUE

FACULTY OF CIVIL ENGINEERING

Department of Construction Management and Economics

MASTER THESIS

May 2019

Bc. Victoria Nabatova

ZADÁNÍ DIPLOMOVÉ PRÁCE

I. OSOBNÍ A STUDIJNÍ ÚDAJE

Příjmení: **Nabatova** Jméno: **Victoria** Osobní číslo: **410275**

Fakulta/ústav: **Fakulta stavební**

Zadávající katedra/ústav: **Katedra ekonomiky a řízení stavebnictví**

Studijní program: **Stavební inženýrství**

Studijní obor: **Projektový management a inženýring**

II. ÚDAJE K DIPLOMOVÉ PRÁCI

Název diplomové práce:

Shromažďování dat infrastrukturních projektů v BIM

Název diplomové práce anglicky:

Infrastructure project data harvesting in BIM

Pokyny pro vypracování:

Diplomová práce bude obsahovat rešerši zahraniční a české literatury s důrazem na použití dat v infrastrukturních projektech. Praktická část se bude věnovat vzniku a převodu dat mezi jednotlivými aktéry v rámci projektu infrastrukturní stavby. Navržené postupy budou ověřeny prostřednictvím případové studie.

Seznam doporučené literatury:

1) Metodiky České agentury pro standardizaci
2) Lukas Klee et. al., 2018, International Construction Contract Law 2nd Edition, Willey.
3) Metodiky Státního fondu dopravní infrastruktury
4) ISO 16739:2013
5) Construction-Operations Building information exchange (COBie) standard data

Jméno a pracoviště vedoucí(ho) diplomové práce:

Ing. Josef Žák, Ph.D., katedra ekonomiky a řízení stavebnictví FSv

Jméno a pracoviště druhé(ho) vedoucí(ho) nebo konzultanta(ky) diplomové práce:

Datum zadání diplomové práce: **26.02.2019** Termín odevzdání diplomové práce: **19.05.2019**

Platnost zadání diplomové práce: ______________

Ing. Josef Žák, Ph.D.	doc. Ing. Renáta Schneiderová Heralová, Ph.D.	prof. Ing. Jiří Máca, CSc.
podpis vedoucí(ho) práce	podpis vedoucí(ho) ústavu/katedry	podpis děkana(ky)

III. PŘEVZETÍ ZADÁNÍ

Diplomantka bere na vědomí, že je povinna vypracovat diplomovou práci samostatně, bez cizí pomoci, s výjimkou poskytnutých konzultací. Seznam použité literatury, jiných pramenů a jmen konzultantů je třeba uvést v diplomové práci.

Datum převzetí zadání Podpis studentky

Statement of Authorship

I hereby certify that the thesis I am submitting is entirely my own original work except where otherwise indicated. I am aware of the Czech Technical University's regulations concerning plagiarism, including those regulations concerning disciplinary actions that may result from plagiarism. Any use of the works of any other author, in any form, is properly acknowledged at their point of use.

Prague, 19.5.2019 ……………………..

Bc. Victoria Nabatova

Acknowledgement

I would like to express my sincere gratitude to my advisor Ing. Josef Žák, Ph.D. for the continuous support he provided towards this research work, for his patience, enthusiasm, and immense knowledge. His guidance was very valuable and helpful.

I would also like to thank my work colleagues for sharing their knowledge and advice. Last but not least, I would like to thank my family for their great support.

Shromažďování dat infrastrukturních projektů v BIM

Infrastructure project data harvesting in BIM

Abstrakt:

Tato diplomová práce je zaměřena na využití dat v infrastrukturních projektech. Práce je rozdělena na teoretickou a praktickou část. První část je věnována rešerši zahraniční a české literatury, která vysvětluje základní pojmy BIM, týkající se managementu a výměny dat. Druhá část je zaměřena na tvorbu a přenos dat mezi různými softwary s cílem zlepšení viditelnosti a rozhodování projektových manažerů v infrastrukturních projektech.

Klíčová slova: BIM, management dat, výměna dat, Společné datové prostředí, viditelnost, AutoCAD, Navisworks, Power BI, COBie

Abstract:

This diploma thesis is focused on data utilization in infrastructure projects. The thesis is divided into a theoretical part and a practical part. The first part is devoted to the Czech and foreign literature search which explains the basic concepts of BIM related to data management and data exchange. The second part is focused on the data creation and transfer across different computer programs with the aim of enabling improved visibility and decision making for Project Managers for infrastructure projects.

Key words: BIM, data management, data exchange, Common Data Environment, visibility, AutoCAD, Navisworks, Power BI, COBie

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Glossary

AIM	Asset Information Model
AIM	Architects Information Model
AIR	Asset information requirements
BEP	BIM Execution Plan
BIM	Building Information Modelling
BrIM	Bridge Information Model
BS	British Standard
BSI	British Standard Institution
BSIM	Building Services Information Model
CAD	Computer Aided Design
CADD	Computer Aided Design and Drafting
CDE	Common Data Environment
COBie	Construction Operations Building Information Exchange
CSA	Czech Standardization Agency
D-B	Design and Build
DAX	Data Analysis Expressions
EIR	Exchange information requirements or Employer's Information Requirements
IDM	Information Delivery Manual
IFC	Industry Foundation Classes
IFD	International Framework for Dictionaries
ISO	International Organization for Standardization
FIM	Facilities Information Model
LTA	Land Transport Authority
MBD	Model-Based Design
NBS	National Building Specification
OIR	Organizational information requirements
PAS	Publicly Available Specification
PBJV	Penta-Ocean Construction Co Ltd – Bachy Soletanche Singapore Pte Ltd Joint Venture
PIM	Project information model

PIR	Project information requirements
RIBA	Royal Institute of British Architects
SIM	Structural Information Model
SQL	Structured Query Language
WIP	Work in Progress
XML	Extensible Markup Language

1. Introduction

Designers and builders, from the very earliest buildings, needed to communicate with each other to establish the requirements and agree what was satisfactory and acceptable. For hundreds of years, the drawing board, pens and papers remained the main means of passing the information, then computers began to widely spread out in the 1970s and people started using them for computer aided design and drafting (CADD / CAD).

Additional information coming along with the drawings has also evolved over time. At first it was printed in catalogues, then CD-ROM based catalogues. Each party, furthermore, had their own information, which was passed onto each other and often lead to costly mistakes due to different ways of processing information. (*Construction Products Association and NBS, 2013*)

Nowadays, in the era of digitalization, it is possible to store all shared data in one place that is accessible to each party and this is where BIM takes its role. Common Data Environment (CDE), being an inseparable part of BIM, can be understood as storage for all data related to the specific project presented in a structured and smart way so there is no misunderstanding between the stakeholders.

This thesis is devoted to data creation, exchange and utilization processes in infrastructure projects. The main goal of the thesis is to improve the visibility of BIM models to enable better decision making, using current engineering software design and analysis platforms. I will describe the method I have developed to extract relevant attribute data from a BIM authoring software and represent it into a web-based dashboard, providing greater visibility to the project controls team or any relevant construction party.

2. Related literature and theoretical focus

Information management, understandably, is highly important for the successful delivery of any construction project, because it involves enormously complex information flows. Undoubtedly, it causes a lot of problems in the industry – time and money loss on claims, increased costs and schedules – due to very complicated and unstructured nature of information flows and exchanges in a typical construction project. The information management problem should be treated with appropriate standards, processes and technologies.

The first part of this thesis focuses on information flows and data management, data exchange and utilization problematics.

2.1 What is BIM – brief introduction

Building Information Modelling (BIM) is an acronym, in which more and more people in the construction industry are becoming increasingly interested. It involves the process of creating, using and managing building data during its lifecycle. BIM is also sometimes referred to as *Building Information Management or Better Information Management*, because it might better reflect the essence of the whole concept. BIM can be spread out to all sectors: building structures, transportation engineering, water structures and civil engineering in general. It is necessary to distinguish BIM as a process, which covers the generation and management of the physical and functional information of a project, and BIM as a model, which is the output and the main product of the process (Koncepce zavádění metody BIM v České republice, 2017).

BIM is closely connected to Model-based Design (MBD), which is "*a mathematical and visual method of addressing problems associated with designing complex systems such as buildings, plants or indeed any other product*" (Kumar, 2015). A considerable advantage of using MBD is cost-effective and efficient approach of making communication and integration between players easier throughout the whole process.

There are many various definitions of BIM. For example, the National Institute of Building Sciences defines BIM as following:

“*Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition.*”

According to Eastman, BIM is *“a modelling technology and associated set of processes to produce, communicate and analyse building models.”* These building models have such characteristics, as smart building components (which “know” what they are and can understand parametric rules); components with data describing how they behave (for analyses), coordinated data (so the change would be reflected in all views) and consistent and non-redundant data (so the change in the component would be reflected in all views of the component). (Eastman et al., 2011)

BIM, undoubtably, implies collaboration between all the stakeholders (Figure 1) with the purpose of connecting teams and having access to the information whenever needed.

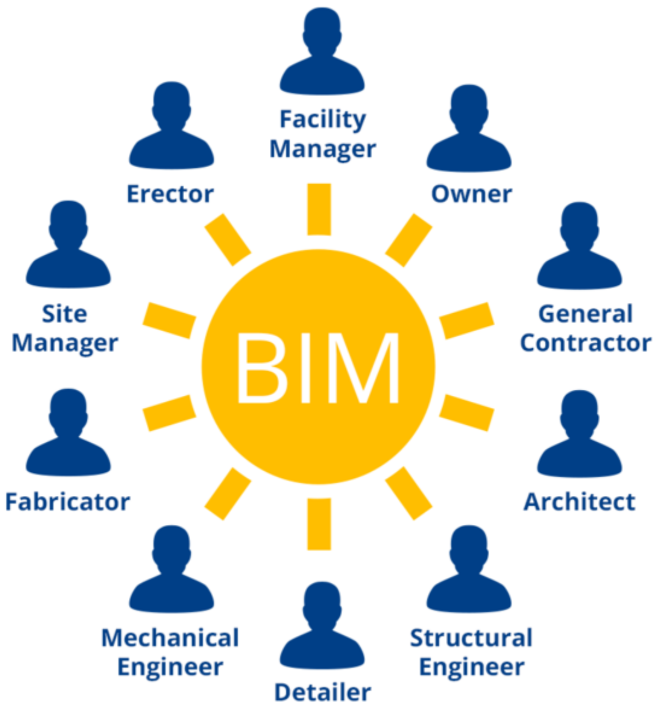


Figure 1 - BIM collaboration (Building in Cloud, 2019)

2.2 BIM Maturity Levels

In the industry it is often talked about BIM with the reference to its maturity levels. They come from the widely used BIM Maturity Diagram developed by Mervyn Richards and Mark Bew in 2008. These levels are illustrated in figure 2 below.

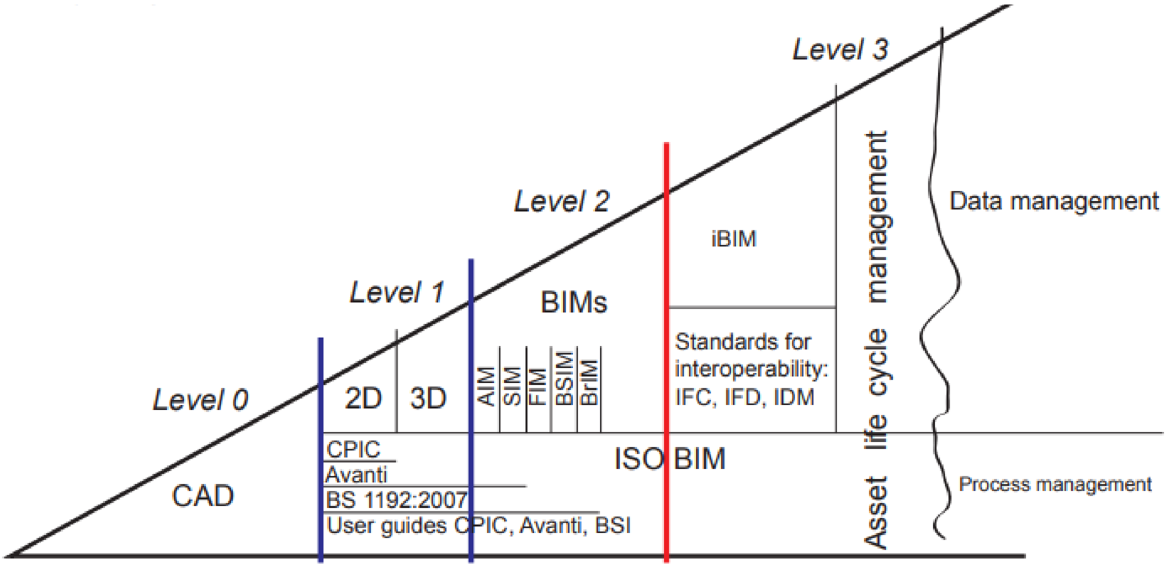


Figure 2 - BIM Maturity Diagram (RIBA,2012)

According to the Maturity Diagram, also called wedge diagram, there are levels 0,1,2 and 3 and they are used as measures of BIM maturity. The complexity and development are increasing with each next level.

Level 0

It is the simplest form of maturity. Level 0 can be defined by no collaboration and the use of 2D CAD drafting only. There is no differentiation between data management and process management – it starts only from level 1. Output (construction drawings) and its distribution is mainly via paper – the whole process as it has been known and used for many years.

Level 1

Level 1 is often referred to as “lonely BIM”. The increased use of 2D information is followed by non-federated 3D models and only one party takes advantage of utilizing the model – meaning there is no collaboration between different disciplines at this stage of BIM maturity.

As for processes, there is a need of having process management and there are advisories, guides and standards to help with that.

Level 2

Level 2 BIM is demanding different Building Information Models (BIMs), such as:

- AIM - Architects Information Model;
- SIM - Structural Information Model;
- FIM - Facilities Information Model;
- BSIM - Building Services Information Model;
- BrIM - Bridge Information Model;

These are being placed in a single shared online area - Common Data Environment. At this stage, originators are using other models as a source for creating their models, which they control. For this level, there should be a discussed and agreed digital information exchange process, which might be based on guides such as PAS 1192-2 or newer. Further requirements include BIM Execution Plan, BIM Protocol, clear definition of EIR (Employer’s Information Requirements or Exchange Information Requirements[1]) and delivery of relevant information and digital models for asset management to the Client.

Level 3

In the last level of BIM maturity, BIM model is seen as a single shared model which is held at centralized depository. iBIM in the graph stands for “integrated Building Information Modelling”. The BIM model represents full collaboration combining all disciplines. Any party can access it and edit the same model, which reduces the risk of conflicting information. The main challenge will not be the collaborative use of information, but data harnessing with the aim of greater use. This level will also require software interoperability: using standards as Industrial Foundation Class (IFC), International Framework for Dictionaries (IFD), The Information Delivery Manual (IDM). In addition to 3D information of the project, there can be attribute data included at level 2 and 3, defined in terms of the multi-dimensional functions (McPartland,2017):

[1] Employer’s Information Requirements were changed to Exchange Information Requirements according to BS EN ISO 19650, released in the first quarter of 2019.

- 3D – creating graphical and non-graphical information; parametric design models – use of spatial dimensions (height, width, length) to represent an object, make visualizations and detect clashes;
- 4D – adding a time parameter to link the individual 3D parts with the timeline of the project, including quantities and resources scheduling;
- 5D – adding costs to models, integration with design, estimations and scheduling;
- 6D – expanding the model with project assets information, supporting facilities management and operational side.

2.3 BIM uses for a construction project – general

When BIM is applied to a project, it is essential to identify its uses for the project according to the targets that the client intends to reach. Each project is unique, but there are some common goals, which may include better process management, design improving, time and money saving due to better coordination and change management. Later the objectives and uses should be stated in BIM Execution Plan so all involved parties have the clear understanding of what to focus on.

There is no single list of uses which is universal and applicable to every project and country, but there are some created by different organizations and agencies.

According to *BIM Project Execution Planning Guide* (Computer Integrated Construction Research Program, 2011), there are twenty-five benefits or BIM Uses identified throughout the building lifecycle for consideration on a project. These benefits are organized by project phase of project development (Plan, Design, Construct, Operate) and divided into primary and secondary BIM Uses and can be seen in the following figure:

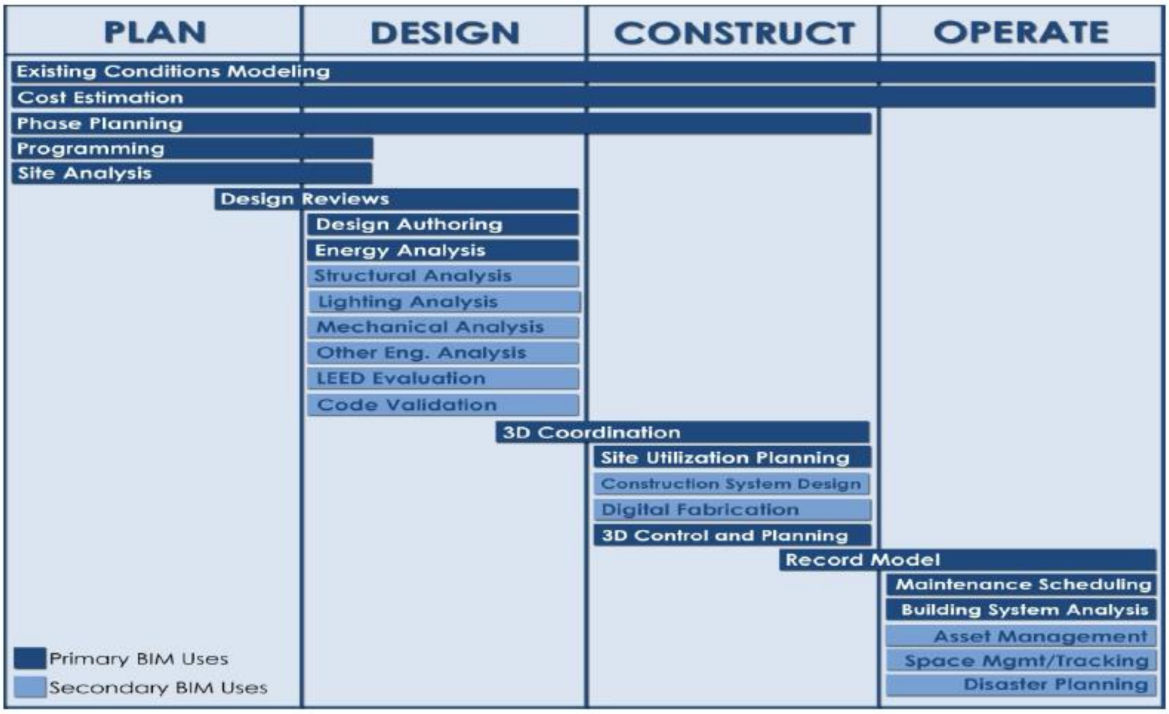


Figure 3 - BIM Uses for a construction project (Computer Integrated Construction Research Program, 2011)

Every use has potential values to bring in, for example, for 3D Coordination it is "*Reduced construction cost; potentially less cost growth (i.e. less change orders); increase productivity on site; coordinate building project through a model"* and others (Penn State CIC, 2018)

For a comparison, Czech Standardization Agency (CSA) made a broader research on BIM Uses in 2018 and described sixty-two (62) BIM Uses that they found (some of them are based on BIM Project Execution Planning Guide, mentioned above). CSA findings are adapted to the Czech Republic project phases, which are eleven – from preparation works and feasibility study to the demolition of the object. Here are some examples of the uses:

- Surveying
- Virtual Reality Simulation (VR)
- 2D, 3D documentation
- Code Checking & Validation
- Quantity take-offs
- Simulation of a construction process
- Space Management
- Collision Detection

- Lighting Analysis
- Visualizations and others.

2.4 BIM Uses for infrastructure projects

The State Fund for Transport Infrastructure (SFDI) in cooperation with Ministry of Industry and Trade of the Czech Republic and other institutions (2018) developed a document on the BIM Uses particularly for infrastructure projects, based on the research mentioned above.

In this document they defined forty (40) BIM applicable Use cases, divided into eight (8) construction phases. Each use was then evaluated for each phase and as a result the matrix with the overall benefit for each use in each phase was created. A cut-out can be seen in figure 4:

Číslo	Užití dat BIM	buildingSMART	BIMDictionary_A	Studie	poznámky	DUR	poznámky	DSP	poznámky	PDPS	poznámky	RDS	poznámky	ZBV	poznámky	DSPS	poznámky	Provozní dokument…	poznámky	Celková poznámka	Průměr užitečnosti	Průměr proveditelnosti	Počet výskytů		Užitek	Užitek s významností
1	Trasa, niveleta			10		10		10		10		10		10		10		10			10.0	1.8	8		8	65
2	Tvorba návrhu ve 3D	-	Tvorba návrhu stavby	8		8		9		10		10		10		9		9		Projektová přípra…	9.0	6.0	8		3	24
3	3D model stávajícího stavu	Tereain modeling		8		9	Inženýrské sítě	9		9		9		9	Inženýrské sítě	9	Propojení se stávají…			Vytvoření (nebo…	9.0	1.9	7		7	50
4	Společné datové prostředí (CDE) a integrace s podnikovými systémy	-	Integrace BIM a ERP			9		9		9		9		9		9		9		Propojení inform…	9.0	4.0	7		5	35
5	Integrace se systémy pro správu a údržbu (doplnění údajů)	Make FM documentation	Integrace BIM/FM													9		9		Propojení inform…	9.0	4.0	2		5	10
6	Automatizace a robotizace výstavby	Control machinery	Logistika výstavby									9		9							9.0	6.5	2		3	5
7	Údaje o výrobcích / elementech, specifikace vlastností							7		10		10		10		8		8		Specifikace elemen…	8.8	3.0	6		6	35
8	Vytváření výkresové dokumentace z modelů	Make production doc.	2D dokumentace	5		8		9		9		9		9		9				Vytvoření 2D výkres…	8.2	4.0	7		4	30
9	3D model stávajících inženýrských sítí			5		9	vzniká v tomto	9		9		9		8						Vytvoření (nebo…	8.2	3.9	6		4	25
10	Výkaz množství	Make quantity take-off	Výkaz výměr	7		8		8		9		9	v podrobnosti	9	Finanční sledov…	9		6		Podklad pro sestav…	8.1	4.9	8		3	26
11	Prohlídky, údržby, revize															8		8		Revize k dotčen…	8.0	2.3	2		6	11
12	Záruky															8		8	záruka konečného	Záruky k elemen…	8.0	2.3	2		6	11
13	Detekce kolizí	Perform consistency control	Detekce kolizí			5		7		9		9		9		8					7.8	2.0	6		6	35
14	Vytvoření konstrukčního modelu	Make Struc. BIM model	-					8		8		8									7.8	5.4	3		2	7
15	Pozemkové vazby (KN)			2		9	stanoví se pozem…	9	se nejen					9	Jen v případě změn…	9				Prokázání vztahu…	7.7	3.0	5		5	23
16	Distribuce informací a řízení dat v rámci povolování a realizace projektu	-	-	5		6		8		9		9		9		8					7.6	4.2	7		3	24
17	Generování plánu údržby a prohlídek	Schedule maintenance	-															7		Automatické genero…	7.3	4.3	1		3	3

Figure 4 - Uses of BIM for infrastructure projects (SFDI et al., 2018)

The BIM Use cases include:

- Terrain modelling
- Generation of a maintenance plan
- Spatial analysis
- 3D utilities model
- Quantity take-offs
- Concrete Precasting
- Construction Logistics
- Urban Planning

- Risk and Hazard Assessment and so on.

2.5 Information requirements and information models

It is necessary to mention that in the first quarter of 2019 there were two international standards of the ISO 19650 series published. The new BS EN ISO 19650-1 and BS EN ISO 19650-2 have superseded BS 1192:2007 + A2:2016 and PAS 1192-2:2013. Nevertheless, they are founded on these standards with just some changes in terminology (BSI, 2018). Although the ISO 19650 is now the recognised latest version, it will take some years for the industry and client to adopt this new standard so in this thesis they are both referred to.

All projects should have a strategy regarding asset management. This brings companies optimization of the whole life cost of managing assets' portfolios, better understanding and awareness of the operational and maintenance needs of assets, better decision-making regarding projects or assets, better planning on different levels and other advantages.

Initially, the Client (can be also called *the appointing party*) should have a vision of what information will be needed to meet goals and objectives of their assets within the project using BIM technology. These requirements would be passed on the delivery teams and can be justified by the following purposes:

- A register of assets – to support reporting and auditing
- Risk management support: e.g. for analysing the exposure to natural hazards, adverse weather events, etc.
- Business questions support: questions concerning ownership and operation of the asset – information for maintenance and repairs, information needed for day to day operations of the asset, renovation information, capacity and utilization management, security and surveillance management.

There are different information types and models for the Client to pay attention to. They are specified in following figure 5 from the new BS EN ISO 19650-1:

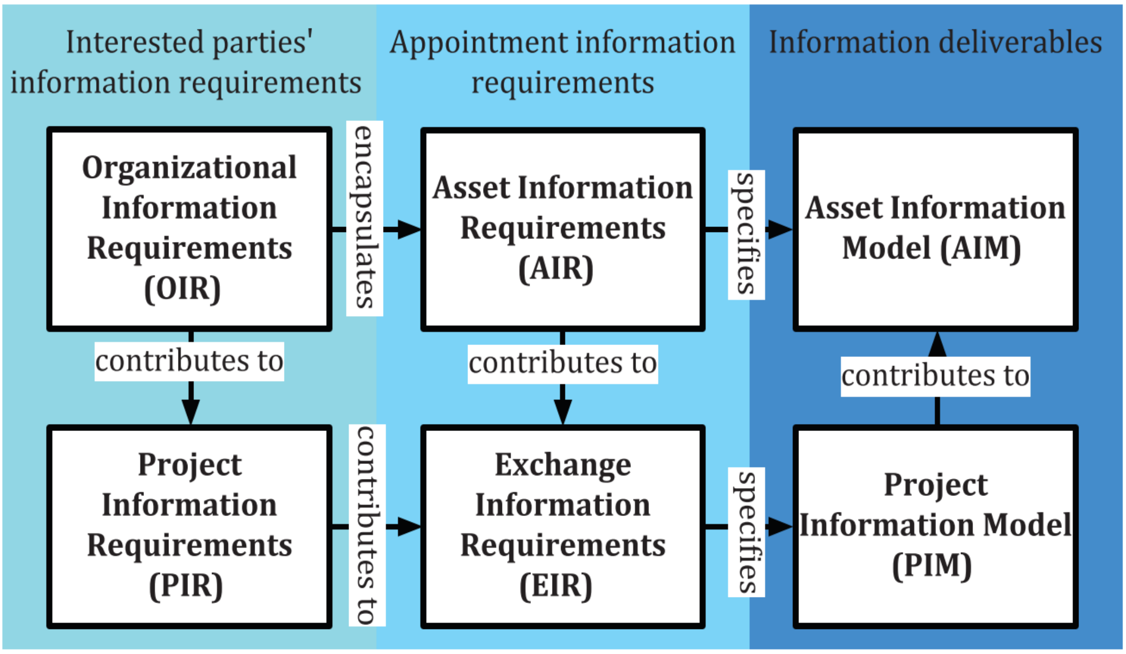


Figure 5 - Information models and types (BSI, 2018)

2.5.1 Organizational information requirements (OIR)

According to PAS 1192-3, organizational information requirements (OIR) explain the information required by an organisation for asset management systems and other organisational functions (BSI, 2014). These requirements, for example, might include strategic business operations analysis, asset management strategy, policy-making, portfolio planning and others. (BSI, 2018)

2.5.2 Asset information requirements (AIR)

Asset information requirements (AIR) are generated based on Organizational Information Requirements. AIR state the requirements of producing asset information. These requirements can be divided into three categories: managerial, commercial and technical. Managerial information might include asset types, identification numbers, location, warranties periods, inspection schedules, emergency plans and other; commercial information might contain supplier details, key performance indicators, performance targets, etc. Technical information is, for example, engineering data, operational data, interdependencies, parameters. (BSI, 2018)

2.5.3 Project information requirements (PIR)

PIR are based on high-level objectives in relation to particular project. It helps the Client to make further decisions during the key points of the project. For that, a proper set of information requirements should be prepared for each such point. PIR newly appears in BS EN ISO 19650, but essentially is an equivalent of *Plain Language Questions (PLQ)* from PAS 1192-3, according to the definition of PLQ (BSI, 2014). Both terms pursue the same goal.

2.5.4 Exchange information requirements (EIR)

The new BS EN ISO 19650 brought a new EIR abbreviation: if before it stood for Employer's Information Requirements in PAS 1192-2 (BSI, 2013), in the new standard it stands for Exchange information requirements. Same as in 2.5.3 these terms correspond and can be seen as equal.

EIR is a tender document stating the requirements of producing projects information and can be divided (same as AIR) into managerial, commercial and technical information in a way that is realistic, achievable, specific and measurable. It serves as the basis for the Contractor to develop the initial BIM Execution Plan (BEP) (Ashworth,2017). EIR takes into account OIR, AIR and PIR and these form the basis of the IER.

2.5.5 Asset information model (AIM) and Project information model (PIM)

These models are deliverables of the whole information requirements' chain. The AIM and PIM represents repositories of information, which is important for decision making during the whole life cycle of an asset. Both models can contain structured and unstructured information. Structural information can be represented by geometrical models, databases and schedules. Unstructured information would be documentation or voice recordings.

The AIM is about supporting day-to-day operations and asset management processes, it can also contribute to the start of the project delivery process (in case of already existing asset, which is often the case). An example of information contained in the AIM would be cumulative maintenance costs, ownership details, equipment registers and other details.

The PIM is about supporting the project delivery and the AIM activities. The PIM can include such information, as project geometry, equipment location, construction method, costing, scheduling.

2.6 The information delivery cycle

The figure below (figure 6) represents the project and asset information life cycle in the context of international standards (BSI, 2018):

- ISO 19650 - *Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) -- Information management using building information modelling*, which has superseded BS 1192:2007+A2:2016 and PAS 1192-2:2013;
- ISO 55000 – *asset management standards*;
- ISO 21500 - *guidance for project management*;
- ISO 9001 – quality management.

Figure 6 - Generic project and asset information management life cycle (BSI, 2018)

The green circle in the middle is the life cycle for delivery and operational phases of an asset. Point A would mean start of delivery phase, point B – development of the design intent model into the virtual model; point C – delivery phase end – transfer of meaningful information to operational phase.

2.7 CDE (Common Data Environment)

It is necessary to set up efficient cooperation between the different parties in construction projects in order to deliver facilities effectively. A lot of organizations nowadays are switching to working in new collaborative environments to reach better quality and better re-use of existing experience. Benefits include higher project teams' productivity and accuracy, more effective communication, data sharing without contradictions and loss. Common Data Environment (CDE) can be used throughout the whole project lifecycle - design, construction, operation, deconstruction.

BIM dictionary defines Common Data Environment as "*a single source of information which collects, manages and disseminates relevant, approved project documents for multidisciplinary teams in a managed process*" and also "*Information within a CDE need to carry one of four labels (or reside within one of four areas): Work In Progress Area, Shared Area, Published Area, and Archive Area*"

The following figure 7 shows the areas and the workflow of Common Data Environment:

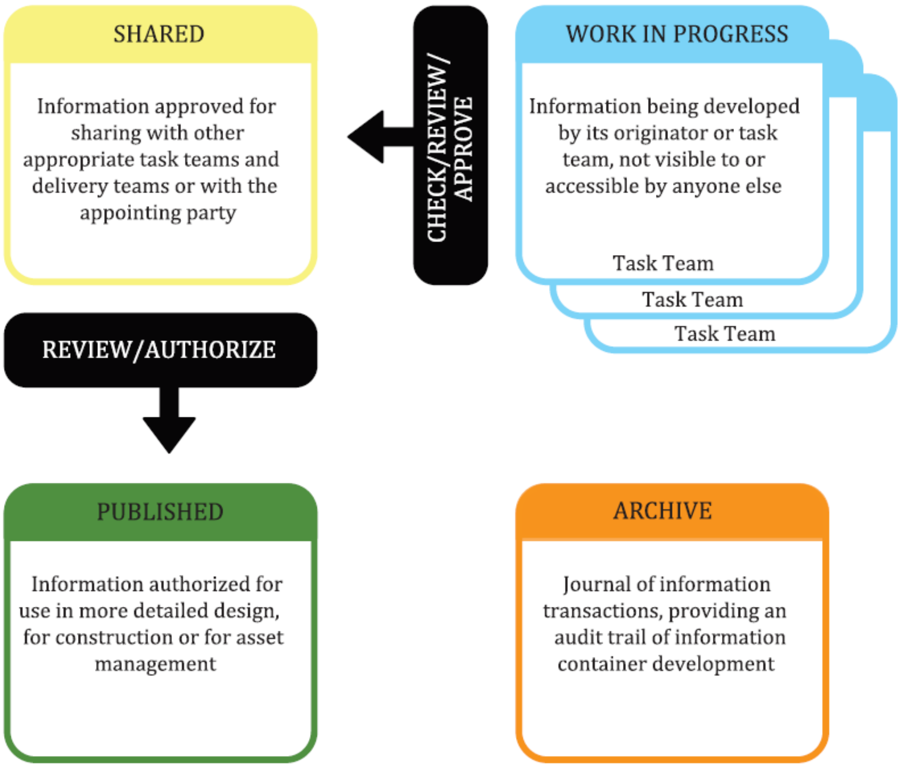


Figure 7 - Common data environment (CDE) schema (BSI, 2018)

According to *BS EN ISO 19650-1:2018* each data container should include following metadata:

- A revision code;
- A status code, which shows the permitted uses of information.

2.7.1 Work in progress

Work in progress, often abbreviated to WIP, is the first area of CDE, which contains design work that is being developed and has not yet been completed, checked or approved. It is important that this information is not available to other teams, especially if a shared system serves as the CDE (e.g. shared server or portal). (*BSI, 2018*)

2.7.2 Shared

Shared area of CDE represents information, which has been shared with other members of the delivery team. The main goal of the shared area is to make the information model development collaborative and productive. The shared data should be visible, but it is not recommended to make it editable. It is also needed to make sure that one should not upload the models several times to avoid misleading information as it is being used as background information by others. If it is necessary to edit the model, it should be returned to the WIP area for its author to review and reupload. The revision code in that case would be changed as well. Adequate appointed parties should check and consult information containers in this state.

The shared area is also being used for sharing data with the appointing party and data waiting for authorization.

2.7.3 Published

Published container can hold information such as validated design outputs to be further used for actual construction or asset management. Documents get published status after being approved or partially approved by the client and can be used for construction.

2.8 Suitability Codes

Suitability Codes or Status Codes are codes that define the purpose of the information being shared as metadata. The information has a particular status depending on the container within the CDE: WIP, Shared, Published or Archived. According to *BS 1192:2007+A2:2016*, the Suitability Codes list is the following (table 1):

Code	Short description
S0	Work in progress (not for sharing)
S1	For coordination
S2	For information
S3	For review and comment
S4	For stage approval
S6	For PIM Authorization
S7	For AIM Authorization
D1	For costing
D2	For tender
D3	For Contractor design
D4	For manufacturer / procurement
A1, A2, A3, An…	Approved and accepted by the client
B1, B2, B3, Bn…	Partial client sign-off with comments
CR	As Construction Record

Table 1 - Suitability Codes from BS 1192:2007+A2:2016 (BSI, 2016)

BS EN ISO 19650:2, which superseded *BS 1192:2007+A2:2016*, gives similar status codes list, except that it does not contain D-codes and contains S5 code – meaning Withdrawn. Despite that, the new standard states that "*This list can be expanded for project-specific codes and fixed within the project information standard*." These suitability codes are not only implemented in the CDE, but also can be found in software, as for example, in Civil 3D UKIE [2] where it can be adapted or used as it is.

2.9 Information and data exchange

The next chapter describes the information exchange on a BIM project and the ways it could be done effectively. It explains the native and Industry Foundation Classes formats and structured data (as COBie files).

[2] Civil 3D Country Kit for United Kingdom & Ireland. Provides access to country-specific reports and templates.

2.9.1 How the data is exchanged

In order to exchange data on a construction project using BIM, each member of the process that provides information – contractor or subcontractor – needs to clearly know what is requested from him to provide, when it is requested and how this information will be used.

During its lifecycle, each construction project will require certain information to be delivered to the client in certain formats at key points. Key points – sometimes called "data drops" – represent milestones of the project, that are important for the Client for analysing of the available information and further decision-making and project controlling.

Even though data drop stages will depend on the particular project and the Client's requests, there are guidance that propose plans. For example, PAS 1192:2 suggests data to be exchanged at the next stages with defined levels of model detail and model information (BS, 2013):

Data drop stage	Levels of model detail and model information
1. Brief	No graphical model or information from the AIM for existing buildings
2. Concept	No real graphical model, 2D drafting or diagrams
3. Design	3D representation of the objects with specifications
4. Definition	The object based on generic representation of the element
5. Build and Commission	Objects procured from the manufacturer instead of generic objects
6. Handover and Closeout	All relevant information about the product; as-built model representing as-built project with the accuracy, regarding the content and dimensions
7. Operation and In-use	The Performance of the project should be compared with the EIR and the brief; in case of conflict, the model should be updated. Furthermore, the model needs to be updated at the in-use stage with all supplementary information, for example, replacement dates, replaced equipment, maintenance records etc.

Table 2 - Data drop stages from PAS 1192:2 (BSI, 2013)

Via data drop the Client might require models in a native and Industry Foundation Classes (IFC) formats, structured data (such as COBie files at the relevant stages with data available) and other timely documents. Both IFC and COBie are described in the further sections. The Client's detailed requirements on a project should be specified in EIR, which was discussed in chapter 2.5

2.9.2 Industry Foundation Classes

Industry Foundation Classes (IFC) is a global standard developed by the buildingSMART organization with aim of facilitating interoperability in the building industry. In its common form IFC is a text ASCII file[3] (buildingSMART, 2019). IFC can be represented as:

- An exchange format;
- A data-model;
- Alternative file formats: e.g. IFCXML, IFCZIP

IFC as an **exchange format** (figure 8), which needs to be understood by the final user, is made to be open, which means it supports sharing, displaying and analysing data across different software applications and different platforms. An IFC file can contain geometrical and non-geometrical data; the whole model or just a subset of the information.

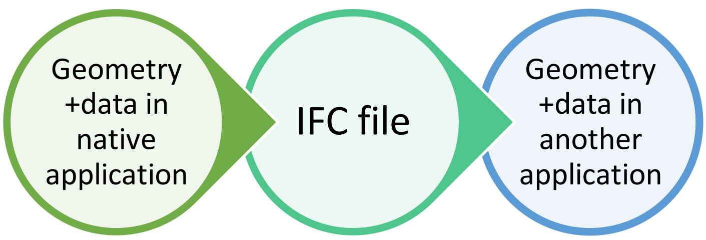


Figure 8 - IFC data exchange

The design team is commonly using IFC for design visualizations and clash detection, the contractors are using it for construction planning, scheduling and take-offs. Moreover,

[3] ASCII - American Standard Code for Information Interchange. An ASCII file is a text file, which contains only the text entered by the user and remains unformatted.

IFC files are serving for an easy referencing or merging of different disciplines during project phases (figure 9).

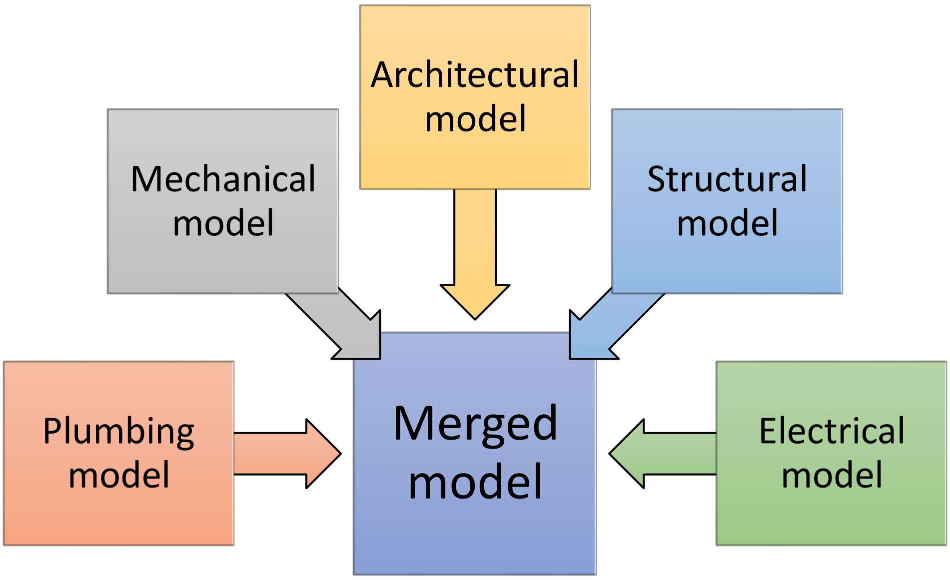


Figure 9 - IFC merged model

IFC as a **data model** would be useful for developers to get to know how the model is built. It is able to describe how a facility is used, how it is constructed and operated and explains the relationship between entities and elements in a model, grouping of elements and components, properties structures. (buildingSMART, 2019)

IFC as IFCXML format is using the same data model as the standard IFC file, but with XML document structure. The advantage of the XML structure is that data exchange from machine to machine can be easier.

2.9.3 Construction Operations Building information exchange (COBie)

The following part describes one of the information exchange projects, called Construction-Operations Building information exchange or COBie, for short. It can be used as a part of data drop during project stages, but its primary use is for maintenance and building operation thanks to a relatively easy way of all valuable data extraction from BIM model to something as simple and familiar as Microsoft Excel spreadsheet.

2.9.3.1 Brief COBie introduction

BIM Dictionary gives the following definition of COBie:

"*COBie (Construction Operations Building Information Exchange) is a specification for the capture and delivery of design/ construction information to Facility Managers.*"

Facility Managers in this definition are implied to be the last link in the chain as they are the ones who are operating, maintaining and tracking assets within the building. The information, that they need in order to do things mentioned above is given by the construction project participants – designers and manufacturers – and even though it is developed by highly skilled engineers, it is mostly never used, because it often comes months or years after the building has been completed and because the data is not in the easy usable way (e.g. paper boxes, CDs…). In order to ease the data maintenance, COBie specification was created. COBie allows to transmit the important information from each significant project participant in required structure in accordance with internationally recognized standards. (East, E. William, 2012)

But before this information reaches Facility Manager or the Client, it is passed between construction parties during different project phases and can be also used for various purposes. Examples of applications of COBie for the Designer can be data and schedules, for the Contractor – procurement of materials, project controlling and tracking.

2.9.4 COBie as a deliverable

How to maintain COBie is explained and well-defined in BS 1192-4:2014 "Collaborative production of information. Part 4: Fulfilling employer's information exchange requirements using COBie – Code of practice" in a form of guidance.

The advantage of COBie is that it provides ***structured*** data. The scope of exchange should be always defined by the Client, when the data exchange is required and by whom it should be delivered.

COBie can be used both for infrastructure and building with several changes in terms. In both cases there is asset (spatial + physical), operational and supplementary information. Asset information consists of such segments as:

- Component – both for buildings and infrastructure;
- Facility – both for buildings and infrastructure;
- Floor (region) – the first one for buildings, the second one for infrastructure;
- Space (location) – the first one for buildings, the second one for infrastructure;
- System – both for buildings and infrastructure;
- Type – both for buildings and infrastructure;
- Zone – both for buildings and infrastructure;

Operational information includes as follows:

- Job – both for buildings and infrastructure;
- Resource – both for buildings and infrastructure;
- Spare – both for buildings and infrastructure;

Supplementary information includes as follows:

- Assembly – both for buildings and infrastructure;
- Attribute – both for buildings and infrastructure;
- Connection – both for buildings and infrastructure;
- Contact – both for buildings and infrastructure;
- Coordinate – both for buildings and infrastructure;
- Document – both for buildings and infrastructure;
- Impact – both for buildings and infrastructure;
- Issue – both for buildings and infrastructure.

For the greatest efficiency and benefitting from COBie, it is recommended to integrate it to the whole life cycle (as part of data drops). To generate such a data drop, several ways exist: *manual*, which can be suitable for manufacturers, but hardly for the whole project; *directly from the native model* – the most exact information; and *indirectly from the native model via IFC* – should be possible to produce a COBie dataset from an IFC model.

2.9.5 The relation between IFC and COBie

COBie might be understood as a subset of the buildingSMART data model, known as IFC. Both formats contain the relevant data about an asset, the difference is that COBie has data more focused on the operational phase of a project and therefore the data is more limited.

Thus, IFC files can be used for the generation of COBie “data drops”, however, there are many challenges related to that. A trial held by National Building Specification (NBS) in the UK in 2012 showed several issues that need to be resolved. The purposes of the trial were to find out whether the IFC file is suitable for making a “data drop”, whether there are data losses and whether it can work in the real life. The test involved four phases: receiving and validating the IFC files; giving a report on the outcome; revalidating the corrected IFC file; producing the COBie spreadsheet out of the corrected file. The feedback given by the participants (such as VINCI Construction UK Ltd, Skanska, BAM, Carillion and other contractors) showed the positive attitude towards this way of data exchange with several questions regarding COBie, like clearance in required level of detail, object naming, a single classification scheme, and a data storage. The participants described weak moments of the process that should be strengthened: IFC import/export, which causes the manual checking; the absence of well-defined model view definition for each COBie data drop; a lot of manual work with MS Excel output.

2.10 Software used

2.10.1 AutoCAD Civil 3D

AutoCAD Civil 3D is a computer program developed by the American software corporation called Autodesk. It is highly used for civil engineering projects and supports Building Information Modelling workflows. Civil 3D is built on AutoCAD’s base and has all its features.

What is possible to create with Civil 3D:

- Highways, tunnels, solid structures;
- Utilities networks;
- Surfaces;
- Storm analysis;

and other infrastructure designs.

How it is used for the thesis project: it is the starting point of the workflow, which is discussed in the practical part of the thesis. The project represents the civil linear structure and different parts are modelled in this software. Civil 3D plays an important role in the process as it is not only used for designing, but also for adding the important data for construction, planning and maintenance.

2.10.2 Navisworks

Navisworks is another program developed by Autodesk corporation. It is primarily used for 3D models’ viewings and coordination, allowing to add mark-ups, comments, measurements and save viewpoints, so later it can be shared with another project party. Navisworks is notable for its support of a broad range of file formats, including DWG (AutoCAD), DGN (MicroStation), RVT (Revit), 3DS (3D Studio Max), IFC (IFC – open format) (Autodesk, 2017).

Some other features Navisworks has:

- Clash detection – is a very used feature of the program. Allows to find clashes within the same model or by testing out different models;
- TimeLiner – brings in 4D simulation of the process of construction or demolition with using time frames and activities;
- Animator – allows to create animations in the model (e.g. walk-through);
- Quantification – quantity take-offs and estimations.

How it is used for the thesis project: the program is not used for any of its primarily functions, but as a provider for a COBie extension.

2.10.3 Microsoft Excel

Microsoft Excel is a well-known and used spreadsheet application by Microsoft Corporation serving for data creation, calculations, organizing, formatting, visualizations and other data management processes.

How it is used for the thesis project: it plays a role of a conductor between COBie and Power BI, which is the last point of the whole workflow. Excel spreadsheet contains all data that Power BI „looks" into and as soon as it is renewed or changed, Power BI will reflect it.

2.10.4 Power BI

Power BI is a cloud-based business analytic service developed by Microsoft Corporation enabling to make analysis and interactive visualizations to most kinds of data. It is aimed to be simple, so the users can interact with it and create their own dashboards and reports.

The service consists of different components:

- Power BI Desktop (used for designing and publishing reports);
- Power BI Service (used mainly for sharing reports within the company environment);
- Power BI Mobile (an application) and several others. (Microsoft, 2019)

In many ways Power BI looks like Excel, but they have some core differences (EDUCBA, 2019):

- Power BI is intended to be easy to use comparing to Excel – it has more user-friendly interface;

- While staying simple, Power BI is focused on building potentially complex data models easily;
- Power BI is providing many visualization tools and customized dashboards for sharing, while Excel is not primarily used for these purposes;
- Power BI is capable of handling bigger datasets, comparing to Excel;
- Power BI allows to make a cross-filtering between charts, while Excel does not – data analysis becomes more understandable for the final user

How it is used for the thesis project: only Power BI Desktop was used as it is base for data construction. It consisted of the following processes shown in figure 10 (Lorenz, 2019):

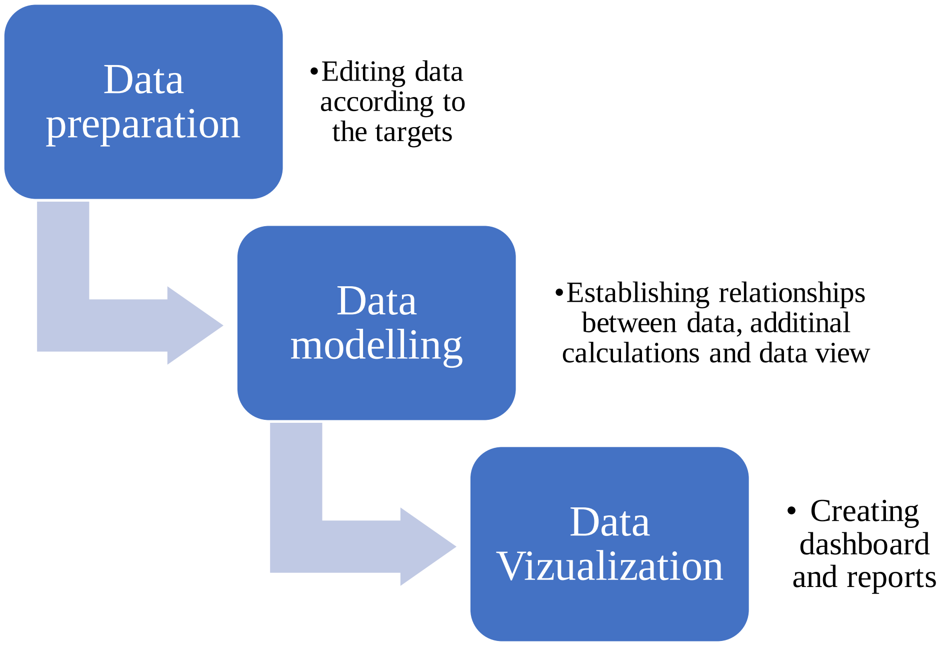


Figure 10 - Workflow within Power BI (Lorenz, 2019)

3. The practical part

The second part of this thesis focuses on data creation, transferring and harvesting across different project parties in infrastructure projects. It is based on a real project of an engineering consulting company with partly simulated data with the aim of establishing workflows, better data control and increasing their visibility. This part represents a proposal for a discussed below project which is very big on its scale and about to be considered to be applied in reality.

3.1 About the chosen project

3.1.1 Basic information

- Name: *North-South Corridor (NSC)*
- Location: *Singapore*
- The Client: *The Land Transport Authority (LTA)*
- The Contractor: *Penta-Ocean Construction Co Ltd – Bachy Soletanche Singapore Pte Ltd Joint Venture (PBJV)*
- Budget for N105 segment: *about S$795 million*
- Works commencement: *the first quarter of 2019*

The chosen project located in Singapore is called North-South Corridor (NSC) and approximately 21.5 km in length, of which approximately 12.5 km is underground cut-and-cover tunnel. It is an expressway, mainly underground, with bus and cycling lanes created to connect towns in the northern region (starting from Admiralty Road) to the city centre (ending at East Coast Parkway) (LTA, 2018). On the following pictures there are several visualizations of the NSC (figure 11 and 12):

Figure 11 **-** *North-South Corridor – Visualization 1 (LTA, 2018)*

Figure 12 **-** *North-South Corridor – Visualization 2 (LTA, 2018)*

The whole project has been divided between different parties to construct and this thesis focuses on one part of the Corridor – N105, which can be seen below in figure 13. It is a 1.04 km-long tunnel and commuter facilities project along Thompson Road. The thesis makes an accent on variety of pipe networks going along with the tunnel.

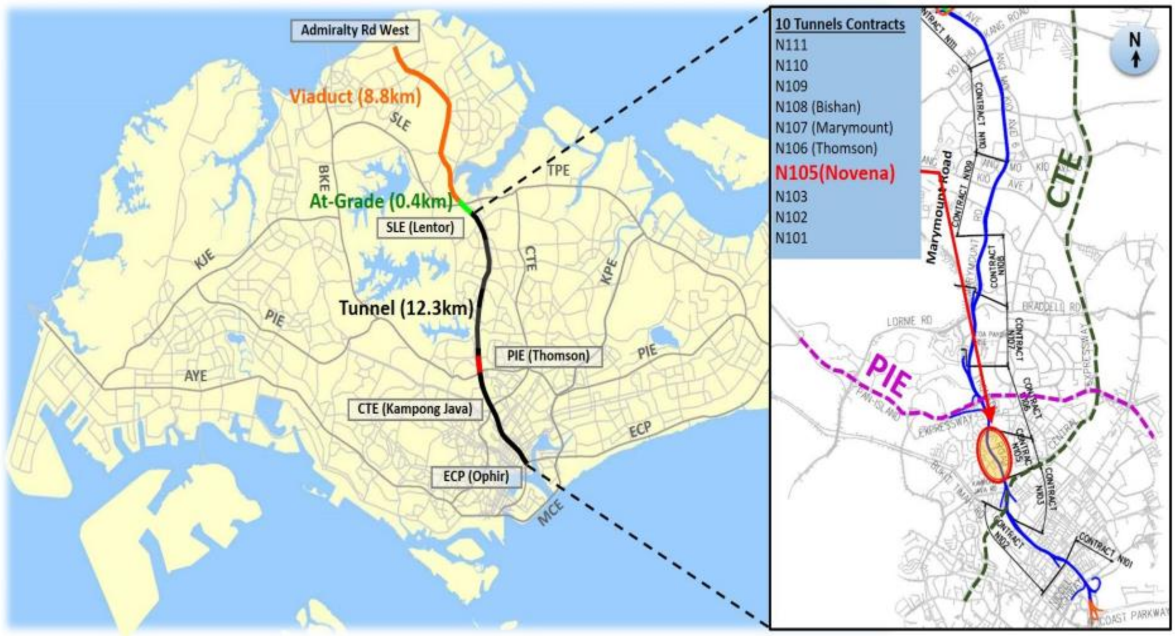


Figure 13 - Location map of NSC alignment (LTA, 2018)

The closer alignment of N105 contract is on the picture below (figure 14):

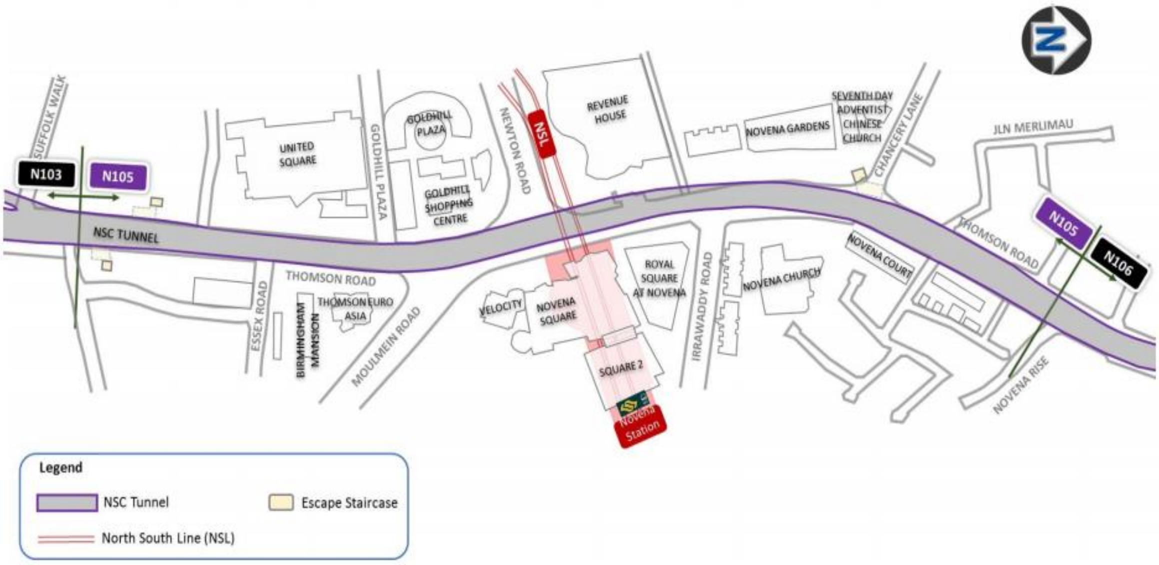


Figure 14 - Location map of NSC tunnel between Suffolk Walk and Novena Rise (LTA, 2018)

3.1.2 BIM objectives and deliverables

The project delivery system chosen is Design-Build (D-B), which means that both design and construction are delivered by the same party. One of the main D-B system advantages in this case is that it allows the contractor to create a design with the application of experience gained before, so that the Client carries less risks.

The project is also using BIM technologies, as it is very hard to coordinate and control all the various disciplines using just traditional 2D drawings, as there are tunnel and road structures, electrical and utilities networks to be designed, including abandoned and existing. Using BIM models will allow to make it easier to control and detect collisions of different networks and change it on time.

Among further key objectives are the design improvement, improving communications with the client, working in collaborative environment, better control of the design through the CDE and safe construction.

3.2 Project design

The project design consists of several disciplines and for each of them there was a separate 3D model created to be later combined into one Building Information Model – so called federated model. This model for NSC N105 includes architectural, electrical, geotechnical, drainage, gas, tunnel & structural models. Below, in figures 15 and 16, there are snapshots of the designed model:

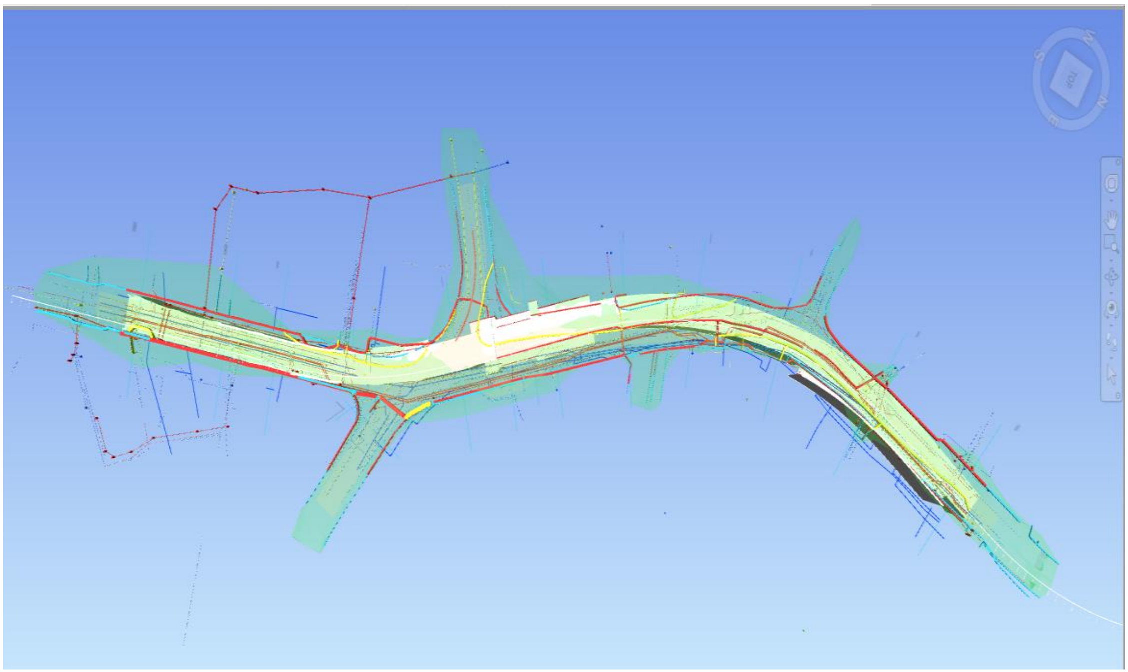


Figure 15 - Project Layout (Autodesk Navisworks)

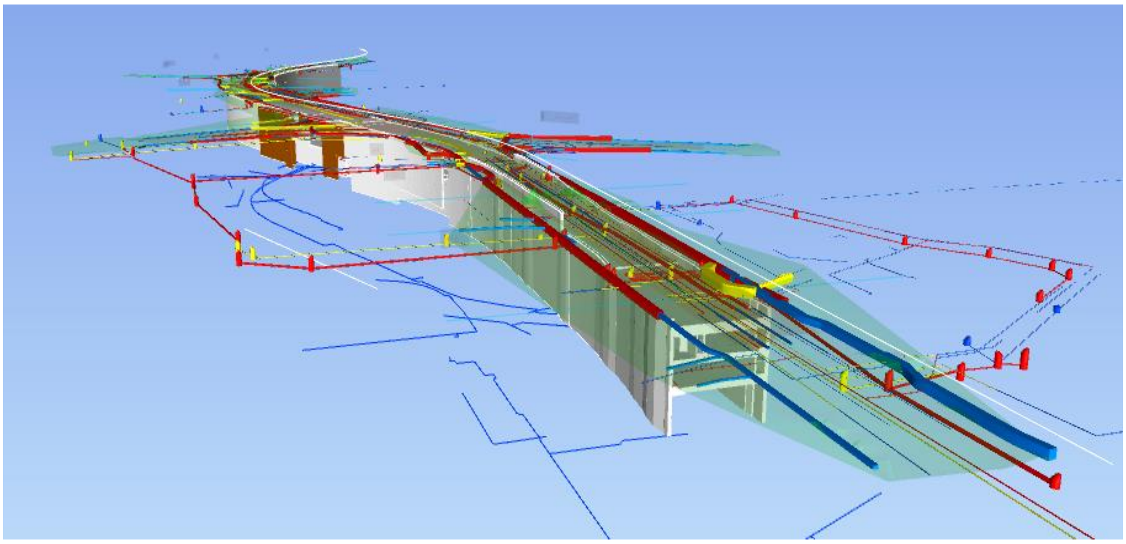


Figure 16 - Federated Model (Autodesk Navisworks)

3.3 Scope of work in thesis

In the thesis I have chosen to take the utilities model and apply the appropriate workflow to it in order to achieve the better visibility of the data leading to the better construction control for the Project Manager. The important point of my practical part is that COBie is used for the continuous following of the project. It should be noted that COBie is not used for an asset management, which is the most common practice. The reason behind that is the lack of information for asset management for this moment.

3.4 Considered workflow

At the beginning, there was a question of which programs and software to use for the project process. As the model was created natively in Civil 3D and the company has its license, I have decided to keep it as a starting point.

The next step was to choose where to transfer data. I was considering InfraWorks and Navisworks, both developed by Autodesk. A big advantage of Infraworks is its capability of processing large amounts of data and being suitable for linear structures. But as it is not compatible with COBie, which is an important element of the workflow, I have chosen to work with Navisworks over InfraWorks.

Another reason for choosing these programs is that the company employees – especially draftsman and designers – constantly attend trainings and courses aimed at improving the workers' efficiency and understanding of the software.

Furthermore, the CDE should be taken into consideration. ProjectWise is an established CDE within the project and it is better to use programs, which are already being used by the project team. CDE is not mentioned in the workflow as it is a pillar of the process.

The company is equipped with all programs mentioned above, so it is not a problem to use them. Company equipped software licences are not bound to any data limit.

3.5 Proposed workflow

As a result of previous considerations, the final workflow is as follows (figure 17):

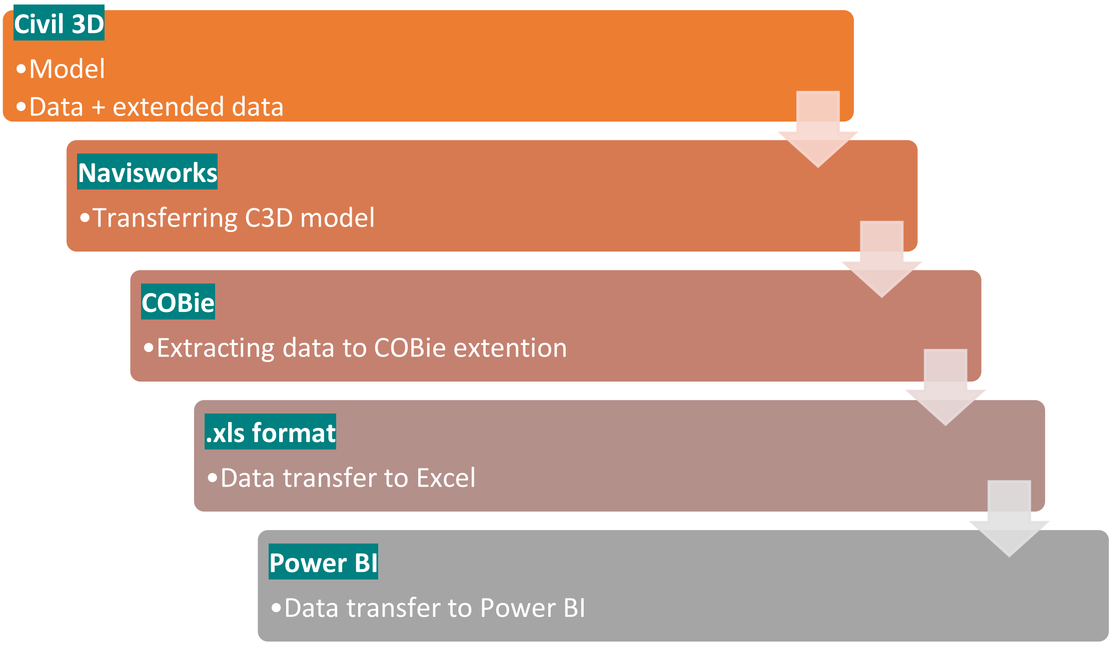


Figure 17 - Proposed workflow for this thesis

Basic data, which can be useful for managing the project during construction phases and asset management phase will be taken from Civil 3D – e.g. pipe ID, material, length, network and others. Additional data, which varies for every project and cannot be measured by software (e.g. pipe network owner, installation date planned and actual, cost and more), will be created and added manually as extended data in order to be filled by any construction party related.

All data needed for the project then will be transferred to Navisworks software, which is primarily used for 3D design simulation and coordination.

COBie extension, which is originally not part of the software needs to be installed and integrated into Navisworks, so all data from Civil 3D can be transferred to it. The following step would be to export it to .xls format document and finally to put the data into Power BI business analytics service.

Understandably, the suggested workflow has its pros and cons and can be adopted as needed according to different project arrangements. As one of examples, there might be no extended data added in the Civil 3D and the COBie input data could be filled on the side by the contractor/subcontractor/any other party involved and then imported to COBie. The following steps would remain the same (figure 18):

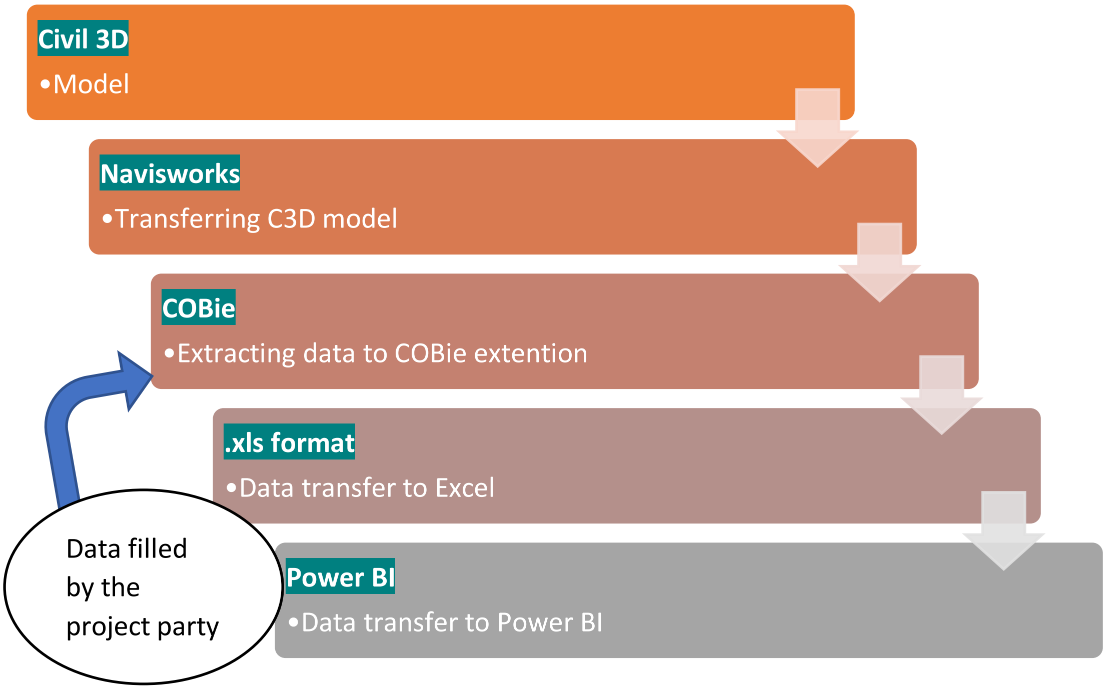


Figure 18 - Alternative workflow

3.6 Project assumptions

The following assumptions were taken for the practical part of the thesis:

- The project data will be updated monthly by the awarded Contractor;
- The project progress will be tracked and updated monthly by the Project Manager via Power BI;
- The abandoned networks are not assumed to be pulled out of the ground or to be interacted with in any way – they are modelled for the purpose of project coordination;
- The existing networks are not intended to be interacted with – they are modelled for the purpose of project coordination;
- The main focus will be on existing networks data;

- The construction will start with the proposed sewer as it is the deepest one to build

3.7 Process

3.7.1 Data and extended data in Civil 3D

The model I have chosen for analysis has been originally created in Civil 3D. There were several pipe networks modelled and then referenced into the separate drawing for the thesis' purpose (figure 19):

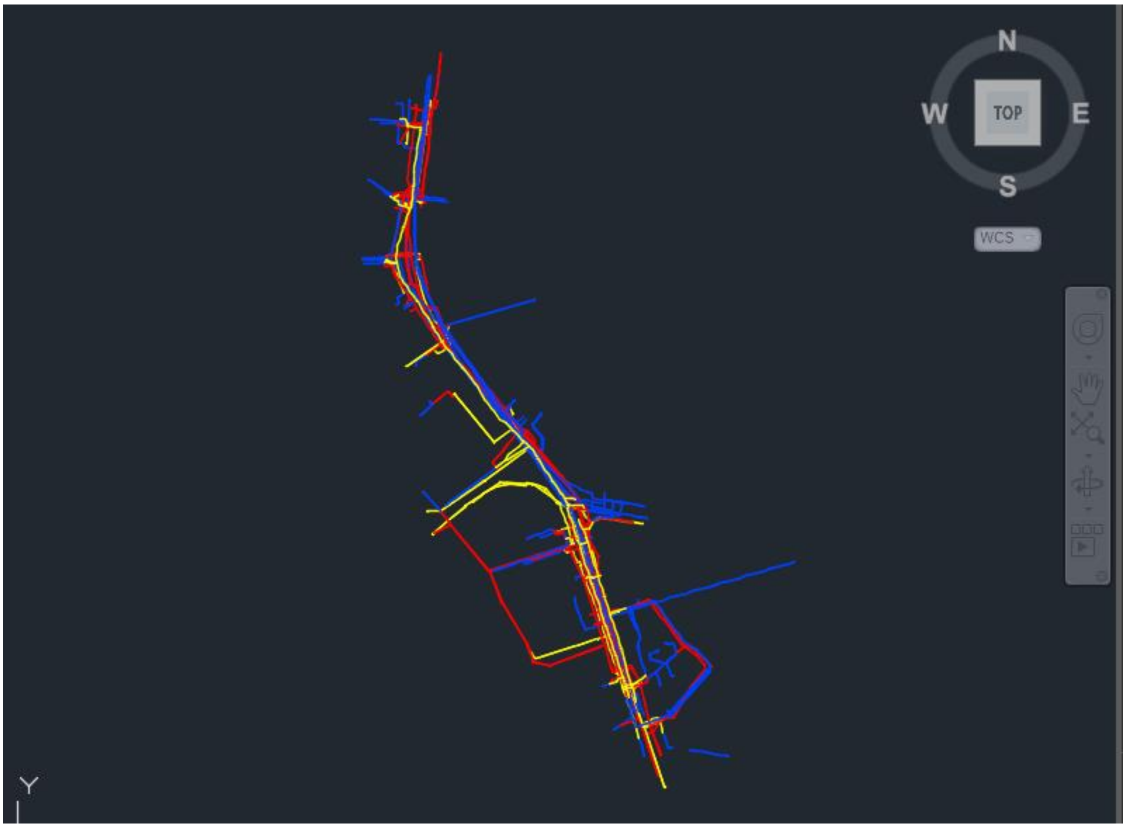


Figure 19 - Pipe networks considered in this thesis3D pipe network model (AutoCAD)

The pipe networks have the relevant layer colour (agreed with the Client in advance), according to the type of network. Yellow was picked for the abandoned networks, for the existing it is blue and red for the proposed. The following networks on this part of the NSC project were requested to be modelled (figure 20):

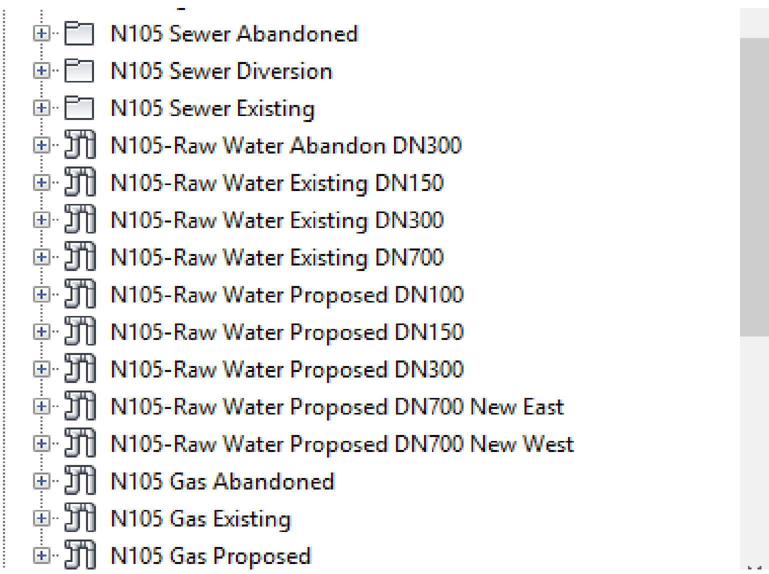
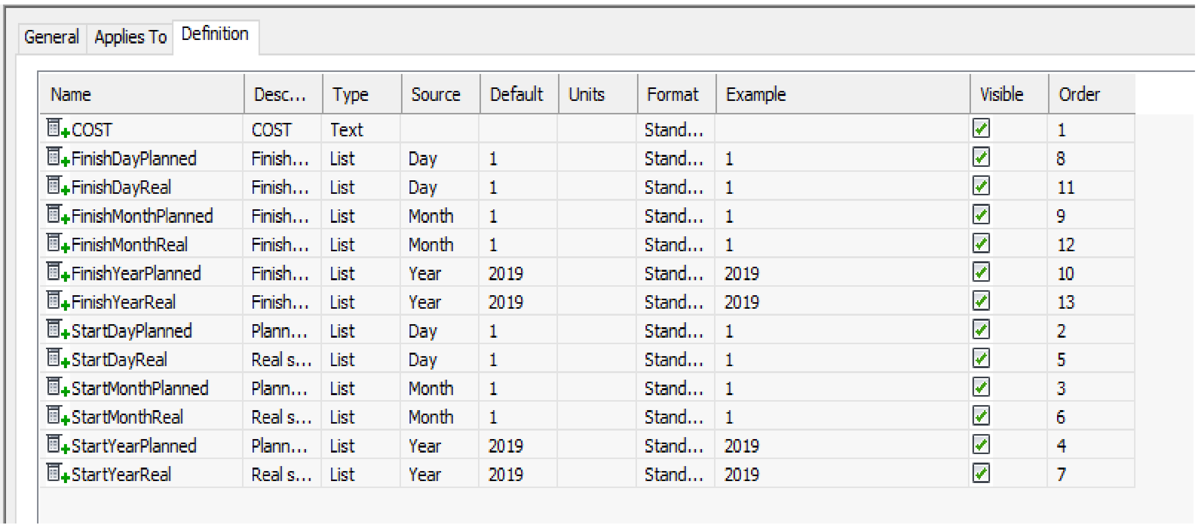


Figure 20 - Pipe networks considered in this thesis (AutoCAD)

All data from the *properties* in Civil 3D are going to be imported into Autodesk Navisworks, but not all of them are important for the Project Manager or the Client. There are also non-geometrical data that needed to be received from the Contractor/Subcontractor for the project control and further asset management and as can be seen in the chosen workflow, these additional non-geometrical data will be added right in the Civil 3D model, as the software allows to do it easily.

There is an “extended data” tab in the properties section and this is where the additional data is added. At first, I added such custom data, as cost, planned installation date: day, month, year; real installation date: day, month, year; planned and actual finish dates. The table can be further extended with any other data that might be required (figure 21).



General | Applies To | Definition

Name	Desc...	Type	Source	Default	Units	Format	Example	Visible	Order
COST	COST	Text				Stand...		✓	1
FinishDayPlanned	Finish...	List	Day	1		Stand...	1	✓	8
FinishDayReal	Finish...	List	Day	1		Stand...	1	✓	11
FinishMonthPlanned	Finish...	List	Month	1		Stand...	1	✓	9
FinishMonthReal	Finish...	List	Month	1		Stand...	1	✓	12
FinishYearPlanned	Finish...	List	Year	2019		Stand...	2019	✓	10
FinishYearReal	Finish...	List	Year	2019		Stand...	2019	✓	13
StartDayPlanned	Plann...	List	Day	1		Stand...	1	✓	2
StartDayReal	Real s...	List	Day	1		Stand...	1	✓	5
StartMonthPlanned	Plann...	List	Month	1		Stand...	1	✓	3
StartMonthReal	Real s...	List	Month	1		Stand...	1	✓	6
StartYearPlanned	Plann...	List	Year	2019		Stand...	2019	✓	4
StartYearReal	Real s...	List	Year	2019		Stand...	2019	✓	7

Figure 21 - Extended data in AutoCAD (AutoCAD)

Besides the supplementary data, there is already existing property set called “Suitability Codes”[4], which is going to be used for tracking down the networks’ parts status (figure 22).

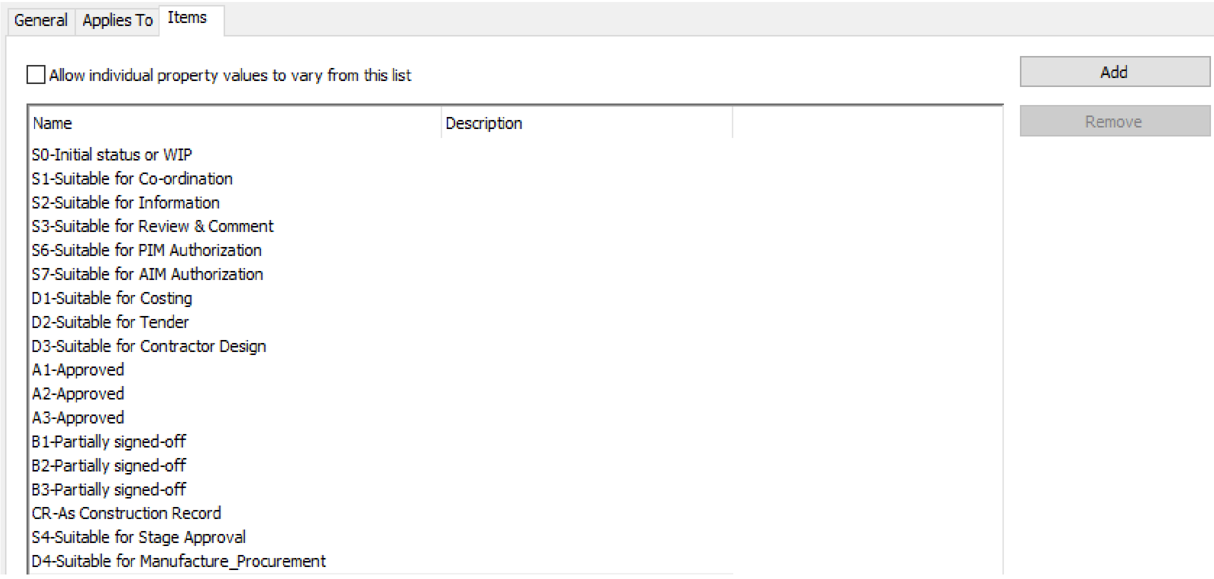


Figure 22 - Suitability Codes in AutoCAD (AutoCAD)

3.7.2 Suitability Codes used for the project

For the project purpose I have decided not to use all codes given in the Civil 3D software due to extra complexity it may bring. Also, I modified codes S1 and B1 description for this thesis purpose. these are the codes (table 3) I used for the progress tracking:

Code	***Description***	***Note***
S0	Initial status or WIP	Design ongoing, pre-approval (either from designer or authority)
S3	Delivered to Client	Waiting for the Client’s approval
A1	Approved	Approved by relevant authority and can be built
B1	Being constructed	In the process of construction
CR	As Construction Record	Asset has been built and verified that it is built in accordance with design

Table 3 - Suitability Codes used for thesis purpose

[4] UKIE Template is used - Civil 3D Country Kit for United Kingdom & Ireland.

3.7.3 Navisworks and COBie processes

After all extended data property sets are prepared in Civil 3D, the Contractor can fill up the data available after the first month and a data drop for the Client can be created.

The updated utilities model can now be exported from Civil 3D as solid objects and imported to Autodesk Navisworks. The Navisworks solid object model retains its intelligence and this data can be extracted using a COBie plug-in developed by Autodesk (figure 23).

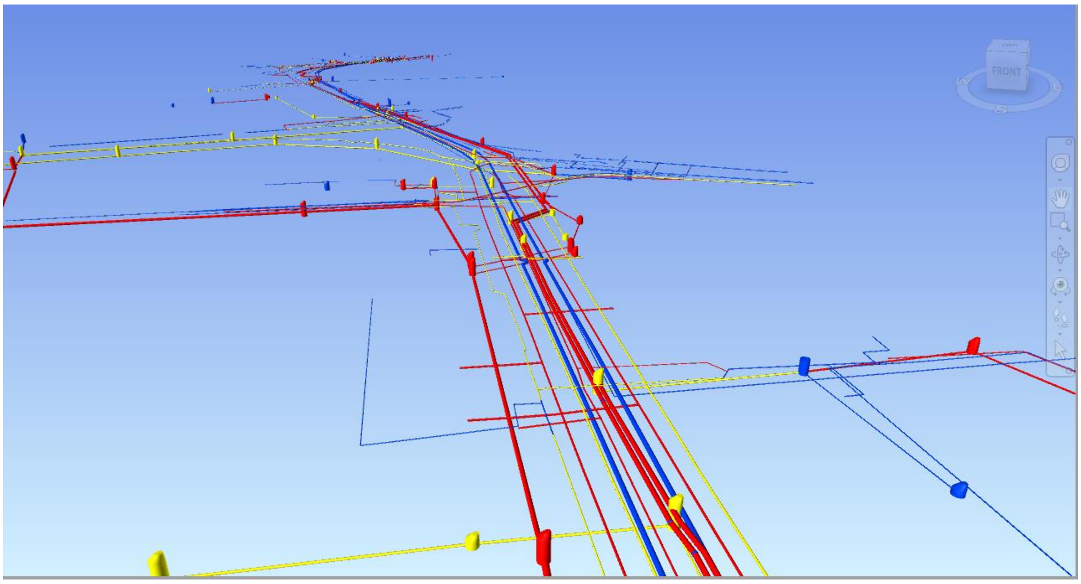


Figure 23 - The model in Navisworks (Autodesk Navisworks)

The initial problem with COBie is that COBie was designed mainly for structural, mechanical and electrical disciplines where software and processes have been developed to provide automated COBie format exports from Revit models. In other words, COBie was developed for use on buildings, rather than infrastructure and, therefore, the information is needed to fit into the structural data drop format, even though COBie might not always be aligned with the structure of such infrastructure projects. It is important for the real application of this workflow to the case.

For a simulation I used only **Type** segment. At first, it was necessary to decide which information is required, or in case of this thesis, wanted to be extracted to COBie spreadsheet for further needs and amendments. I decided to extract the following geometrical basic information:

- Item name
- Description

- Layer
- Length
- Material

Also, I decided to take the following non-geometrical information:

- Status (Suitability code);
- Planned and actual start day;
- Planned and actual start month;
- Planned and actual start year;
- Planned and actual finish day;
- Planned and actual finish month;
- Planned and actual finish year.

I created and configured a new data drop template by filling in the relevant asset properties from the model data into each data section of the template (figure 24).

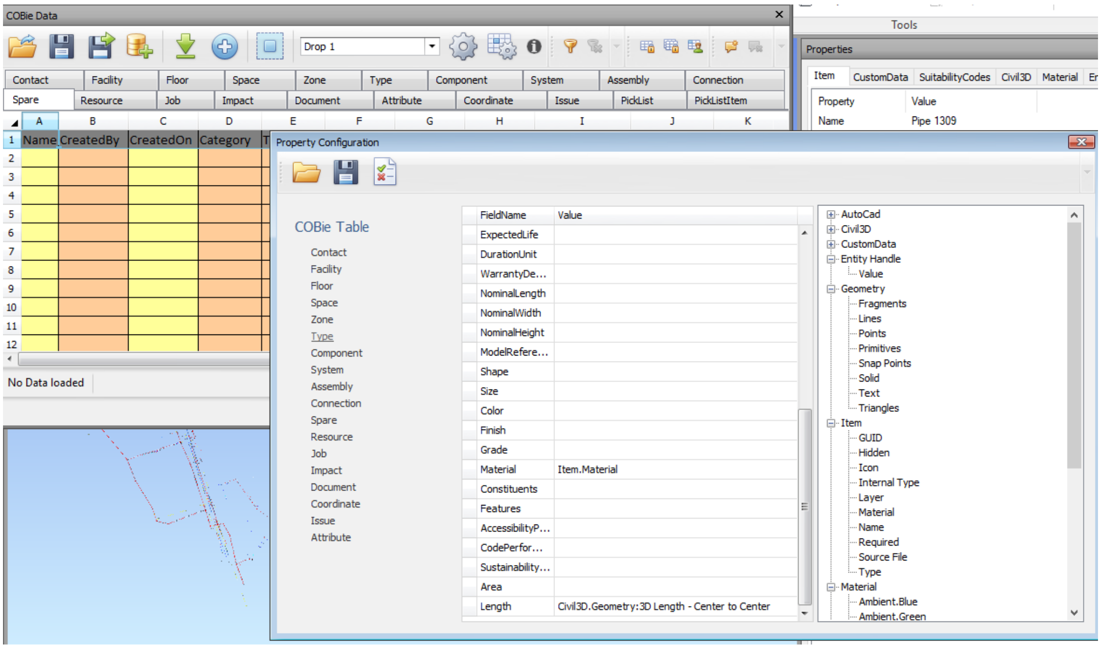


Figure 24 - COBie template (Autodesk Navisworks)

As I mentioned before, I used only Type segment of the template as I do not need much data exported for the further work (figure 25):

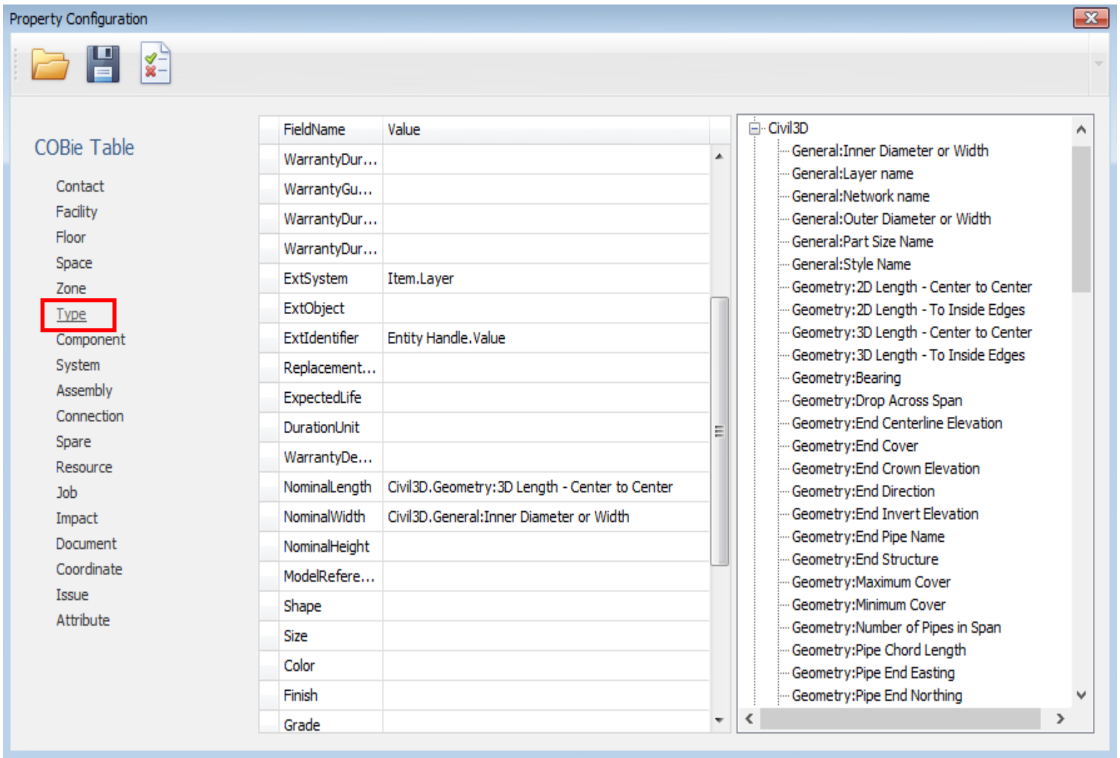


Figure 25 - COBie template configuration (Autodesk Navisworks)

When it was completed, the data were loaded from the model into the COBie format spreadsheet (figure 26).

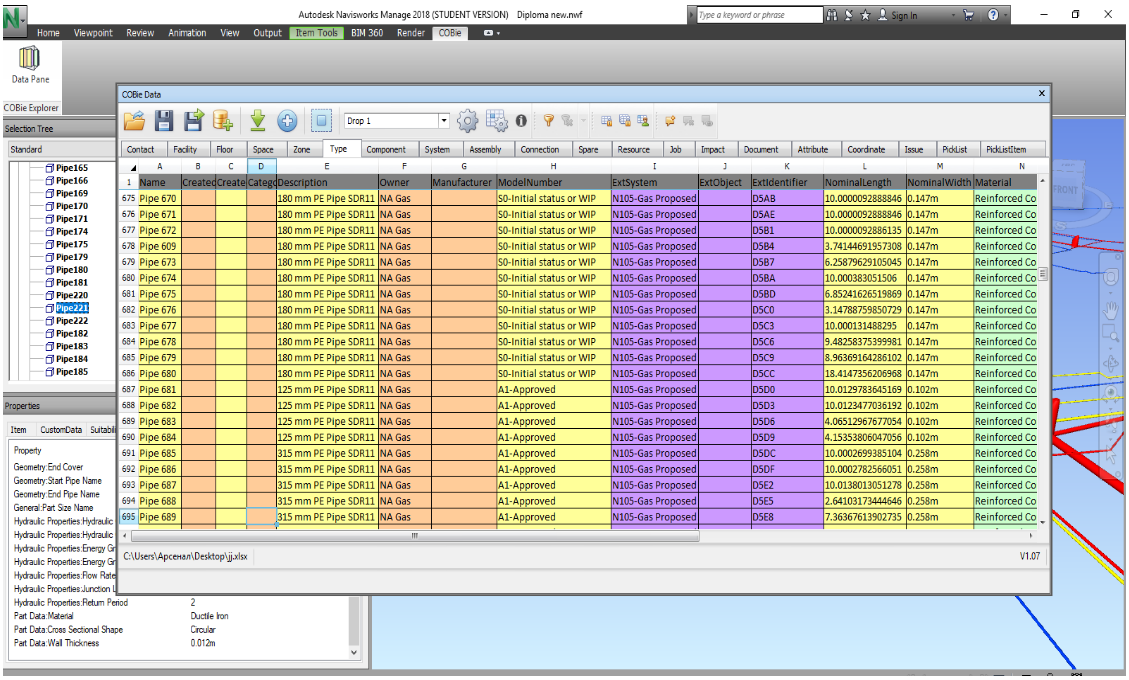


Figure 26 - COBie spreadsheet in Navis (Autodesk Navisworks)

Finally, the COBie spreadsheet was extracted to Excel for checking (figure 27). It is important to mention, that as it is a simulation for the thesis, the columns can easily be renamed after the data are imported into the COBie format spreadsheet (if there are no relevant columns in COBie configuration template) without an agreement with the Client, in reality it would need to be discussed and agreed in advance.

1	Name	Description	Owner	ExtSystem	ExtIdentifier	NominalLength	NominalWidth	Material	Status
5	Pipe 610	250 mm PE Pipe SDR11	NA Gas	N105-Gas Proposed	D4F4	10.0000934441602	0.205m	Reinforced Concrete	S0-Initial status or WIP
6	Pipe 611	250 mm PE Pipe SDR11	NA Gas	N105-Gas Proposed	D4F7	10.0000934437206	0.205m	Reinforced Concrete	S0-Initial status or WIP
7	Pipe 612	250 mm PE Pipe SDR11	NA Gas	N105-Gas Proposed	D4FA	10.0000934441602	0.205m	Reinforced Concrete	S0-Initial status or WIP
8	Pipe 613	250 mm PE Pipe SDR11	NA Gas	N105-Gas Proposed	D4FD	10.0000934438742	0.205m	Reinforced Concrete	S0-Initial status or WIP
9	Pipe 614	250 mm PE Pipe SDR11	NA Gas	N105-Gas Proposed	D500	10.0000934441602	0.205m	Reinforced Concrete	S0-Initial status or WIP
10	Pipe 615	250 mm PE Pipe SDR11	NA Gas	N105-Gas Proposed	D503	10.0000934437206	0.205m	Reinforced Concrete	S0-Initial status or WIP
11	Pipe 616	250 mm PE Pipe SDR11	NA Gas	N105-Gas Proposed	D506	9.19250495538942	0.205m	Reinforced Concrete	S0-Initial status or WIP
12	Pipe 617	250 mm PE Pipe SDR11	NA Gas	N105-Gas Proposed	D509	0.807580985293769	0.205m	Reinforced Concrete	S0-Initial status or WIP
13	Pipe 608	250 mm PE Pipe SDR11	NA Gas	N105-Gas Proposed	D50C	10.0000005307184	0.205m	Reinforced Concrete	S0-Initial status or WIP
14	Pipe 618	250 mm PE Pipe SDR11	NA Gas	N105-Gas Proposed	D50F	10.0000005313116	0.205m	Reinforced Concrete	S0-Initial status or WIP
15	Pipe 619	250 mm PE Pipe SDR11	NA Gas	N105-Gas Proposed	D512	5.99624031770118	0.205m	Reinforced Concrete	S0-Initial status or WIP
16	Pipe 620	250 mm PE Pipe SDR11	NA Gas	N105-Gas Proposed	D515	4.00378215974775	0.205m	Reinforced Concrete	S0-Initial status or WIP
17	Pipe 621	250 mm PE Pipe SDR11	NA Gas	N105-Gas Proposed	D518	10.0000553464579	0.205m	Reinforced Concrete	S0-Initial status or WIP
18	Pipe 622	250 mm PE Pipe SDR11	NA Gas	N105-Gas Proposed	D51B	9.75255321448842	0.205m	Reinforced Concrete	S0-Initial status or WIP
19	Pipe 623	250 mm PE Pipe SDR11	NA Gas	N105-Gas Proposed	D51E	10.2476019786527	0.205m	Reinforced Concrete	S0-Initial status or WIP
20	Pipe 624	250 mm PE Pipe SDR11	NA Gas	N105-Gas Proposed	D521	10.008777208401	0.205m	Reinforced Concrete	S0-Initial status or WIP
21	Pipe 625	250 mm PE Pipe SDR11	NA Gas	N105-Gas Proposed	D524	10.0003664152912	0.205m	Reinforced Concrete	S0-Initial status or WIP
22	Pipe 626	250 mm PE Pipe SDR11	NA Gas	N105-Gas Proposed	D527	10.0108893630975	0.205m	Reinforced Concrete	S0-Initial status or WIP
23	Pipe 627	250 mm PE Pipe SDR11	NA Gas	N105-Gas Proposed	D52A	10.0000987721276	0.205m	Reinforced Concrete	S0-Initial status or WIP
24	Pipe 628	250 mm PE Pipe SDR11	NA Gas	N105-Gas Proposed	D52D	10.000098772275	0.205m	Reinforced Concrete	S0-Initial status or WIP
25	Pipe 629	250 mm PE Pipe SDR11	NA Gas	N105-Gas Proposed	D530	10.0000987721276	0.205m	Reinforced Concrete	S0-Initial status or WIP
26	Pipe 630	250 mm PE Pipe SDR11	NA Gas	N105-Gas Proposed	D533	10.0000987727167	0.205m	Reinforced Concrete	S0-Initial status or WIP
27	Pipe 631	250 mm PE Pipe SDR11	NA Gas	N105-Gas Proposed	D536	10.0000987721276	0.205m	Reinforced Concrete	S0-Initial status or WIP
28	Pipe 632	250 mm PE Pipe SDR11	NA Gas	N105-Gas Proposed	D539	10.000098772275	0.205m	Reinforced Concrete	S0-Initial status or WIP
29	Pipe 633	250 mm PE Pipe SDR11	NA Gas	N105-Gas Proposed	D53C	10.0000987721276	0.205m	Reinforced Concrete	S0-Initial status or WIP
30	Pipe 634	250 mm PE Pipe SDR11	NA Gas	N105-Gas Proposed	D53F	10.000098772275	0.205m	Reinforced Concrete	S0-Initial status or WIP
31	Pipe 635	250 mm PE Pipe SDR11	NA Gas	N105-Gas Proposed	D542	10.0000987725692	0.205m	Reinforced Concrete	S0-Initial status or WIP
32	Pipe 636	250 mm PE Pipe SDR11	NA Gas	N105-Gas Proposed	D545	8.90652563739386	0.205m	Reinforced Concrete	S0-Initial status or WIP

... Floor | Space | Zone | Type | Component | System | Assembly | Connection | Spare | Resource | Job | Impa ...

Figure 27 - COBie spreadsheet in Excel (Microsoft Excel)

The further step is to transfer data from Excel to Power BI service. As Power BI is the final point of the workflow, I decided to make all data modifications there rather than in Excel spreadsheet.

3.7.4 Power BI

Power BI is a relatively new program. As was mentioned before it has a lot of analytical functions and data visibility tools. The possibilities Power BI provides are immense and diversified. I mainly focused on visualising two significant points which matter during the construction phase of the project: *time and costs*.

I have intended to create several dashboards with different content:

1) One with the project overview – for informative purposes;
2) Another with the project time and costs tracking – for control purposes;
3) A final one with the data status tracking – for control purposes.

3.7.4.1 Data preparation

Data preparation is the first out of three steps to go through in Power BI application. It is about importing and modifying data in order to make further work with data smoother.

It allows to take data from many different sources, like Excel, SQL Server, Web, Power BI datasets and so on. I, in this thesis, use only Excel files as a source.

At first, I linked to Power BI an Excel file containing the full dataset for the project overview (for the first dashboard). This data is organised in a data table in Power BI and I only left the necessary columns: pipe name, description, network, length and material. Such a table in Power BI is called a query – it requests information from the source, in this case it is the Excel file, and returns the result as a table.

The query looks as follows (figure 28):

Name	Description	PipeNetwork	NominalLength	Material
Pipe 1141	150 mm Ductile Iron Pipe	N105-Raw Water Existing DN150	10	Ductile Iron
Pipe 1144	150 mm Ductile Iron Pipe	N105-Raw Water Existing DN150	10	Ductile Iron
Pipe 1145	150 mm Ductile Iron Pipe	N105-Raw Water Existing DN150	10	Ductile Iron
Pipe 1152	150 mm Ductile Iron Pipe	N105-Raw Water Existing DN150	10	Ductile Iron
Pipe 1153	150 mm Ductile Iron Pipe	N105-Raw Water Existing DN150	10	Ductile Iron
Pipe 1154	150 mm Ductile Iron Pipe	N105-Raw Water Existing DN150	10	Ductile Iron
Pipe 1159	150 mm Ductile Iron Pipe	N105-Raw Water Existing DN150	10	Ductile Iron
Pipe 1160	150 mm Ductile Iron Pipe	N105-Raw Water Existing DN150	10	Ductile Iron
Pipe 1161	150 mm Ductile Iron Pipe	N105-Raw Water Existing DN150	10	Ductile Iron
Pipe 1165	150 mm Ductile Iron Pipe	N105-Raw Water Existing DN150	10	Ductile Iron
Pipe 1166	150 mm Ductile Iron Pipe	N105-Raw Water Existing DN150	10	Ductile Iron
Pipe 1167	150 mm Ductile Iron Pipe	N105-Raw Water Existing DN150	10	Ductile Iron
Pipe 1168	150 mm Ductile Iron Pipe	N105-Raw Water Existing DN150	10	Ductile Iron
Pipe 1169	150 mm Ductile Iron Pipe	N105-Raw Water Existing DN150	10	Ductile Iron
Pipe 1170	150 mm Ductile Iron Pipe	N105-Raw Water Existing DN150	10	Ductile Iron
Pipe 1171	150 mm Ductile Iron Pipe	N105-Raw Water Existing DN150	10	Ductile Iron
Pipe 1174	150 mm Ductile Iron Pipe	N105-Raw Water Existing DN150	10	Ductile Iron
Pipe 1177	150 mm Ductile Iron Pipe	N105-Raw Water Existing DN150	10	Ductile Iron
Pipe 1184	150 mm Ductile Iron Pipe	N105-Raw Water Existing DN150	10	Ductile Iron
Pipe 1185	150 mm Ductile Iron Pipe	N105-Raw Water Existing DN150	10	Ductile Iron
Pipe 1186	150 mm Ductile Iron Pipe	N105-Raw Water Existing DN150	10	Ductile Iron
Pipe 1187	150 mm Ductile Iron Pipe	N105-Raw Water Existing DN150	10	Ductile Iron
Pipe 1188	150 mm Ductile Iron Pipe	N105-Raw Water Existing DN150	10	Ductile Iron

Figure 28 - Basic information query (Power BI)

For the overview I decided to leave all pipe networks data. It means that I included abandoned and existing networks, in spite of the fact that they have been modelled for coordination purpose only. It is mentioned on the dashboard, named “Overview”.

For the next dashboard this information is irrelevant, so as a following step I deleted the abandoned and existing networks data from the Excel file and reuploaded it into Power BI. The main table contains such data as a *pipe name, description, network, lengths, start* *dates planned and actual, finish dates planned and actual (January through May), cost per given length*. Some data needed to be modified – it is important for further work. For example, dates added in AutoCAD extended data resulted in three different columns (day, months, year) for each of the following: planned start date, actual start date, planned and actual finish dates. In Power BI I needed to merge the day, month and year columns to create one and mark it as "date" data type (figure 29).

	Name	Description	Owner	PipeNetwork	ExtI...	NominalLength	No...	Material	StartDatePl...	StartD...
525	Pipe 2019	300 mm Ductile Iron Pipe	GA Water	N105-Raw Water Prop...	E32A	0.0588091448386832	0.300m	Ductile Iron	4/2/2019	4/11/2019
526	Pipe 2020	300 mm Ductile Iron Pipe	GA Water	N105-Raw Water Prop...	E32D	1.52374250896462	0.300m	Ductile Iron	4/2/2019	4/11/2019
527	Pipe 2022	300 mm Ductile Iron Pipe	GA Water	N105-Raw Water Prop...	E330	5.98125942512305	0.300m	Ductile Iron	4/2/2019	4/11/2019
528	Pipe 2023	300 mm Ductile Iron Pipe	GA Water	N105-Raw Water Prop...	E333	10.001313951557	0.300m	Ductile Iron	4/2/2019	4/11/2019
529	Pipe 2025	300 mm Ductile Iron Pipe	GA Water	N105-Raw Water Prop...	E336	2.78078490579048	0.300m	Ductile Iron	4/2/2019	4/11/2019
530	Pipe 2026	300 mm Ductile Iron Pipe	GA Water	N105-Raw Water Prop...	E339	7.21963644256416	0.300m	Ductile Iron	4/2/2019	4/11/2019
531	Pipe 2028	300 mm Ductile Iron Pipe	GA Water	N105-Raw Water Prop...	E33C	10.000000034849	0.300m	Ductile Iron	4/2/2019	4/11/2019
532	Pipe 2029	300 mm Ductile Iron Pipe	GA Water	N105-Raw Water Prop...	E33F	7.60505633247719	0.300m	Ductile Iron	4/2/2019	4/11/2019
533	Pipe 2031	300 mm Ductile Iron Pipe	GA Water	N105-Raw Water Prop...	E342	2.52254344569954	0.300m	Ductile Iron	4/2/2019	4/11/2019
534	Pipe 2032	300 mm Ductile Iron Pipe	GA Water	N105-Raw Water Prop...	E345	9.88482618845094	0.300m	Ductile Iron	4/2/2019	4/11/2019
535	Pipe 2033	300 mm Ductile Iron Pipe	GA Water	N105-Raw Water Prop...	E348	10.6997271829636	0.300m	Ductile Iron	4/2/2019	4/11/2019
536	Pipe 2034	300 mm Ductile Iron Pipe	GA Water	N105-Raw Water Prop...	E34B	9.3123861792824	0.300m	Ductile Iron	4/2/2019	4/11/2019
537	Pipe 2036	300 mm Ductile Iron Pipe	GA Water	N105-Raw Water Prop...	E34E	0.76670963240736	0.300m	Ductile Iron	4/2/2019	4/11/2019
538	Pipe 2037	300 mm Ductile Iron Pipe	GA Water	N105-Raw Water Prop...	E351	2.94968799473087	0.300m	Ductile Iron	4/2/2019	4/11/2019
539	Pipe 2039	300 mm Ductile Iron Pipe	GA Water	N105-Raw Water Prop...	E354	1.49228208881348	0.300m	Ductile Iron	4/2/2019	4/11/2019
540	Pipe 2040	300 mm Ductile Iron Pipe	GA Water	N105-Raw Water Prop...	E357	1.90133926778184	0.300m	Ductile Iron	4/2/2019	4/11/2019
541	Pipe 2041	300 mm Ductile Iron Pipe	GA Water	N105-Raw Water Prop...	E35A	2.89571544456819	0.300m	Ductile Iron	4/2/2019	4/11/2019

Figure 29 - Proposed networks query (Power BI)

Next, I imported the table from Excel with all project suitability codes for five months to show the changes in statuses timewise and moneywise. The query snapshot is shown in figure 30:

Name	PipeNetwork	Status	CheckDate	ParameterDate
Pipe 1958	N105-Raw Water Prc	A1-Approved	*Friday, February 1, 2019*	*Wednesday, May 1, 2019*
Pipe 2134	N105-Raw Water Prc	A1-Approved	*Friday, February 1, 2019*	*Wednesday, May 1, 2019*
Pipe 2035	N105-Raw Water Prc	A1-Approved	*Friday, February 1, 2019*	*Wednesday, May 1, 2019*
Pipe 2133	N105-Raw Water Prc	A1-Approved	*Friday, February 1, 2019*	*Wednesday, May 1, 2019*
Pipe 2021	N105-Raw Water Prc	A1-Approved	*Friday, February 1, 2019*	*Wednesday, May 1, 2019*
Pipe 2132	N105-Raw Water Prc	A1-Approved	*Friday, February 1, 2019*	*Wednesday, May 1, 2019*
Pipe 2030	N105-Raw Water Prc	A1-Approved	*Friday, February 1, 2019*	*Wednesday, May 1, 2019*
Pipe 2131	N105-Raw Water Prc	A1-Approved	*Friday, February 1, 2019*	*Wednesday, May 1, 2019*
Pipe 2038	N105-Raw Water Prc	A1-Approved	*Friday, February 1, 2019*	*Wednesday, May 1, 2019*

Figure 30 - Suitability codes query (Power BI)

I also created a date parameter to make reports dynamic. As my work is focused on time and costs tracking, I created a list of five dates, which are supposed to show the state of the project according to the chosen date. The project has started in the first quarter of

2019 and five months have passed until the moment of writing the thesis (May 2019). The parameter list is shown in figure 31 below:

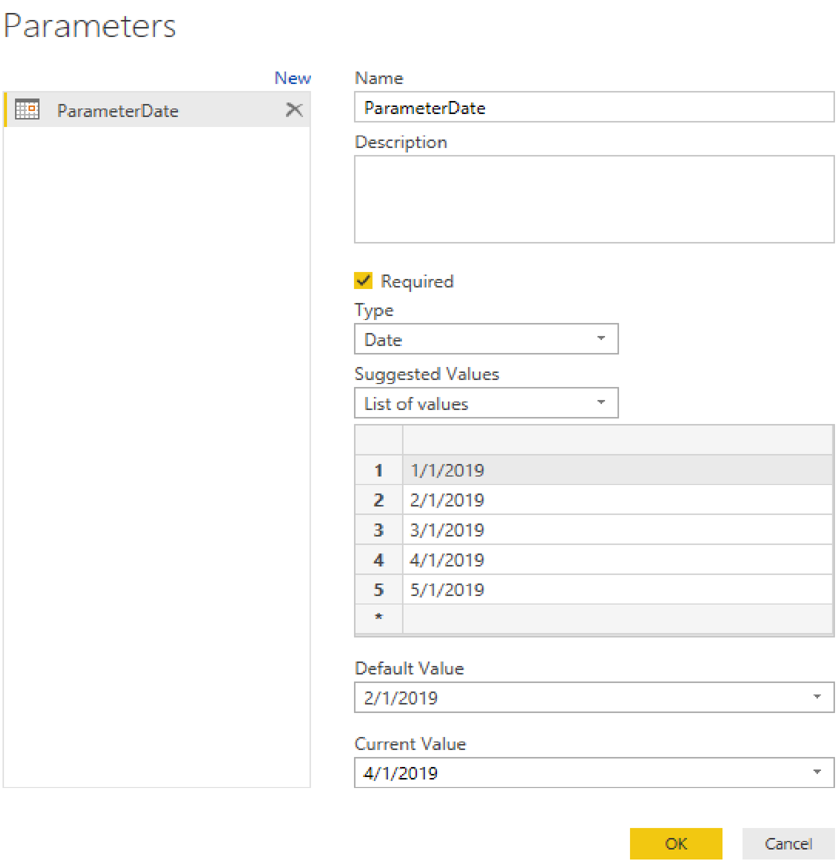


Figure 31 - Parameter configuration (Power BI)

After these modifications I considered data ready for the next step, which is a data modelling.

3.7.4.2 Data modelling

Data modelling is an important and probably the most complex stage of Power BI program as it involves additional calculations, measurements, data relationship establishment and coding (using DAX language, which is a library of functions and operations that can build the formulas). The complexity of modelling stage depends on what is required to be shown in a report.

For the first query *"BasicInfo"*, which contains data for the first dashboard (Overview) only, I added a measure of the total length of each pipe network or the sum of all networks, which can be seen in figure 32:

```
1 TotalLength = FORMAT(SUM('BasicInfo'[NominalLength]),"#,### m")
```

Name	Description	PipeNetwork	NominalLength	Material
Pipe 1141	150 mm Ductile Iron Pipe	N105-Raw Water Existing DN150	10	Ductile Iron
Pipe 1144	150 mm Ductile Iron Pipe	N105-Raw Water Existing DN150	10	Ductile Iron

Figure 32 - Formula correcting the length format (Power BI)

The reason to that is the wrong format that Power BI was showing by default. There is a comparison below (figure 33). On the left, there is a format that is by default, and, on the right, there is a format needed:

22.56K	22,557 m
NominalLength	TotalLength

Figure 33 - Default format versus the right format (Power BI)

This is the only thing that I added in this table.

Next, the main data query which I called *"ProjectData",* required more modelling. As there is a time factor, several columns were added:

- Parameter date column – represents the added earlier parameter with a date which I want to use as a milestone to track the progress and costs;
- Logical test 1, which says: if a compared date greater or equals planned finish date, then put 1 in a cell, if not – 0;
- Logical test 2, which says: if a compared date greater or equals actual finish date, then put 1 in a cell, if not – 0.

An example can be seen below in figure 34:

StartDatePlanned	StartDateActual	FinishDatePlanned	FinishDateActual	LogTest1	LogTest2	ParameterDate
Tuesday, April 2, 2019	Thursday, April 11, 2019	Tuesday, April 30, 2019	Sunday, May 5, 2019	0	0	Monday, April 1, 2019
Tuesday, April 2, 2019	Thursday, April 11, 2019	Tuesday, April 30, 2019	Sunday, May 5, 2019	0	0	Monday, April 1, 2019
Tuesday, April 2, 2019	Thursday, April 11, 2019	Tuesday, April 30, 2019	Sunday, May 5, 2019	0	0	Monday, April 1, 2019
Tuesday, March 5, 2019	Friday, March 8, 2019	Sunday, March 31, 2019	Wednesday, April 10, 2019	1	0	Monday, April 1, 2019
Tuesday, March 5, 2019	Friday, March 8, 2019	Sunday, March 31, 2019	Wednesday, April 10, 2019	1	0	Monday, April 1, 2019
Tuesday, March 5, 2019	Friday, March 8, 2019	Sunday, March 31, 2019	Wednesday, April 10, 2019	1	0	Monday, April 1, 2019
Tuesday, March 5, 2019	Friday, March 8, 2019	Sunday, March 31, 2019	Wednesday, April 10, 2019	1	0	Monday, April 1, 2019
Tuesday, March 5, 2019	Friday, March 8, 2019	Sunday, March 31, 2019	Wednesday, April 10, 2019	1	0	Monday, April 1, 2019

Figure 34 - Data modelling: logical tests (Power BI)

After that I created the table which represents the project completion and refers to the main data table. I named it *"ProjectCompletionTable"*. The first columns are about a date (figure 35). They return the earliest planned start, actual start, latest planned and actual end. Later, it is easy to construct the simple schedule out of these data.

PipeNetwork	PlanStart	ActualStart	PlanEnd	ActualEnd
N105-Gas Proposed	3/5/2019 12:00:00 AM	3/8/2019 12:00:00 AM	9/12/2019 12:00:00 AM	9/12/2019 12:00:00 AM
N105-Raw Water Proposed DN100	9/12/2019 12:00:00 AM	9/12/2019 12:00:00 AM	9/12/2019 12:00:00 AM	9/12/2019 12:00:00 AM
N105-Raw Water Proposed DN150	3/5/2019 12:00:00 AM	3/8/2019 12:00:00 AM	9/12/2019 12:00:00 AM	9/12/2019 12:00:00 AM
N105-Raw Water Proposed DN300	3/5/2019 12:00:00 AM	3/8/2019 12:00:00 AM	12/12/2019 12:00:00 AM	12/12/2019 12:00:00 AM
N105-Raw Water Proposed DN700	3/5/2019 12:00:00 AM	3/8/2019 12:00:00 AM	5/12/2020 12:00:00 AM	5/12/2020 12:00:00 AM
N105-Sewer Proposed	1/5/2019 12:00:00 AM	1/6/2019 12:00:00 AM	2/28/2019 12:00:00 AM	3/2/2019 12:00:00 AM

Figure 35 - Project completion table: part 1 (Power BI)

Next five columns refer to the *"ProjectData"* table as well (figure 36). Thanks to that, the percentage of planned and actual completion can be seen and analyzed.

TotalNoPipes	LogicTest1	%CompletionPlanned	LogicTest2	%CompletionActual
225	49	22%	49	22%
13	0	0%	0	0%
109	45	41%	44	40%
313	18	6%	0	0%
115	15	13%	0	0%
124	124	100%	124	100%

Figure 36 - Project completion table: part 2 (Power BI)

The last five columns are about the project costs (figure 37). It gives the total value of each network costs and compares planned and actual costs. Two last columns show the percentage of the whole project completion planned and actual.

TotalCost	CostPlanned	CostActual	%ComplPlanTot	%ComplActualTot
$1,583,045.23	$344,752.07	$344,752.07	5.45%	5.45%
$5,211.22	$0.00	$0.00	0.00%	0.00%
$68,776.79	$28,394.09	$27,763.11	5.01%	4.89%
$390,517.81	$22,457.89	$0.00	2.00%	0.00%
$882,916.36	$115,163.00	$0.00	1.67%	0.00%
$2,575,002.15	$2,575,002.15	$2,575,002.15	13.79%	13.79%

Figure 37 - Project completion table: part 3 (Power BI)

Regarding the *"Statuses"* query, I added several formulas to take the relevant length and cost value when the parameter date equals the relevant date in the table (figure 38 and 39).

NominalLength	ProjectStatusRelevantLenght
10	10
10	10

```
1  ProjectStatusRelevantLenght = IF('Statuses'[CheckDate]='Statuses'[ParameterDate],'Statuses'[NominalLength])
```

Figure 38 - Data modelling: adding the formula to return the value of length (Power BI)

Cost	ProjectStatusRelevantCost
$10,000.09	$10,000.09
$10,000.09	$10,000.09

```
ProjectStatusRelevantCost = IF('Statuses'[CheckDate]='Statuses'[ParameterDate],'Statuses'[Cost])
```

Figure 39 - Data modelling: adding the formula to return the value of costs (Power BI)

The data modelling is finished, and the data is prepared for the next step which is the visualization.

3.7.4.3 Data visualization

Data visualization is the last step of working with Power BI. It is about revealing insights that have been found in the data and constructing dashboards and reports in a way that is easy to navigate, analyse and understand. There are a lot of useful visuals that are built into the program and can be used directly from Power BI pane. Visuals are the tools helping to create various charts, schemas and graphs (figure 40).

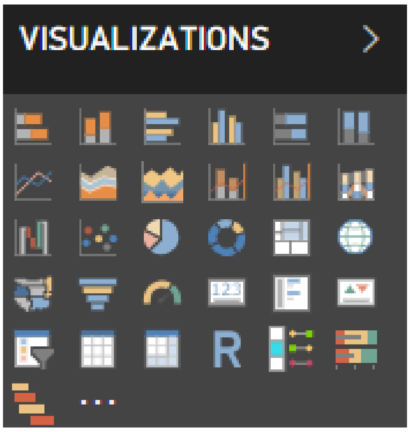


Figure 40 - Power BI visualizations (Power BI)

In the **first** page I constructed a simple project overview dashboard and visualized the pipe networks information. There are four visualizations:

- Each pipe network length chart (“clustered column chart”);

- A list with all the networks (“table”);
- A card, which sums up each pipe network length (“card”);
- Material (“pie chart”).

The snapshot below (figure 41) contains all visualizations mentioned above:

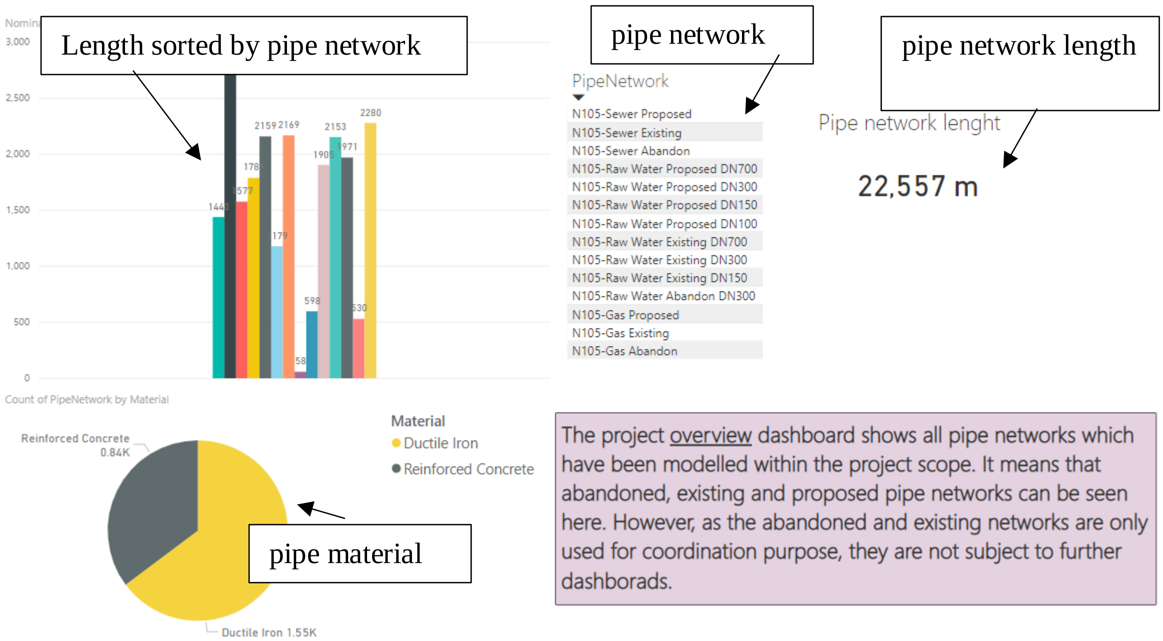


Figure 41 - Project overview dashboard (Power BI)

Closer snapshots (figure 42 and 43):

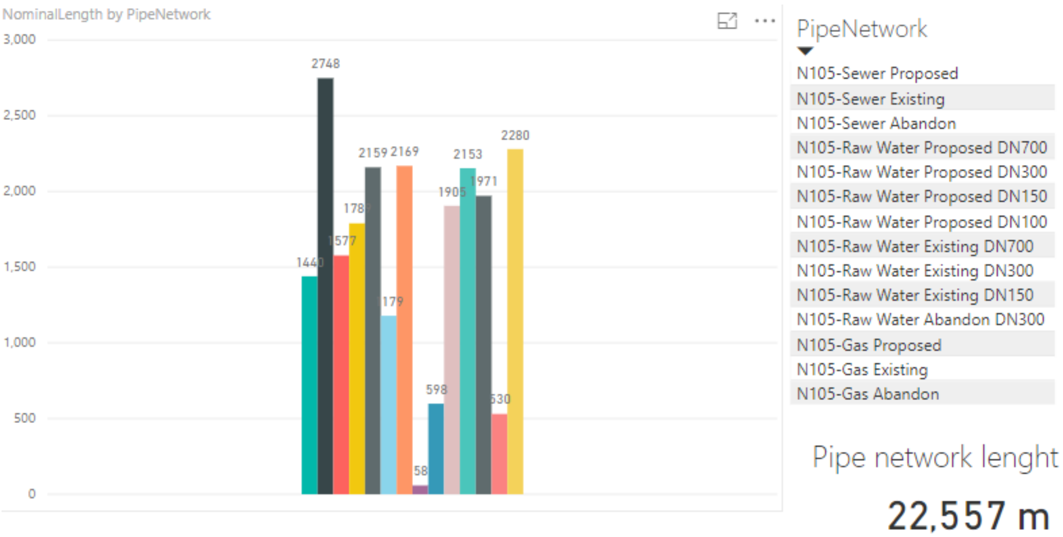
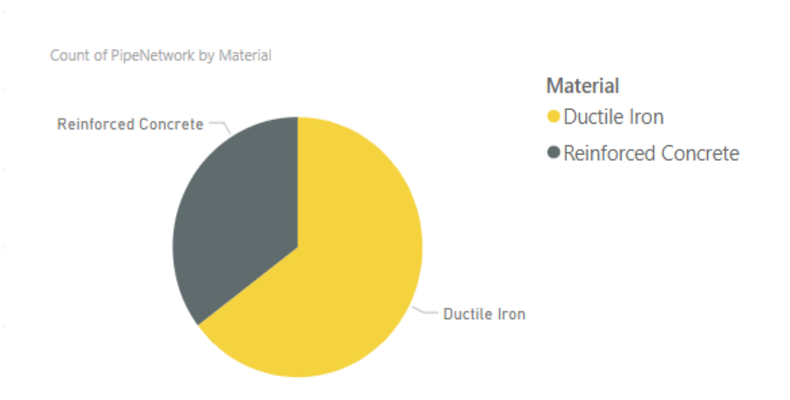


Figure 42 - Project overview: pipe networks and lengths (Power BI)



The project overview dashboard shows all pipe networks which have been modelled within the project scope. It means that abandoned, existing and proposed pipe networks can be seen here. However, as the abandoned and existing networks are only used for coordination purpose, they are not subject to further dashborads.

Figure 43 - Project overview: pipe materials and the note (Power BI)

The visualizations are interactive, and by pressing on any network on the list or in the graph the relevant information will be highlighted. In the case below, *N105 Gas Existing* pipe network is chosen (figure 44). Therefore, all other visualizations are showing the relevant values:

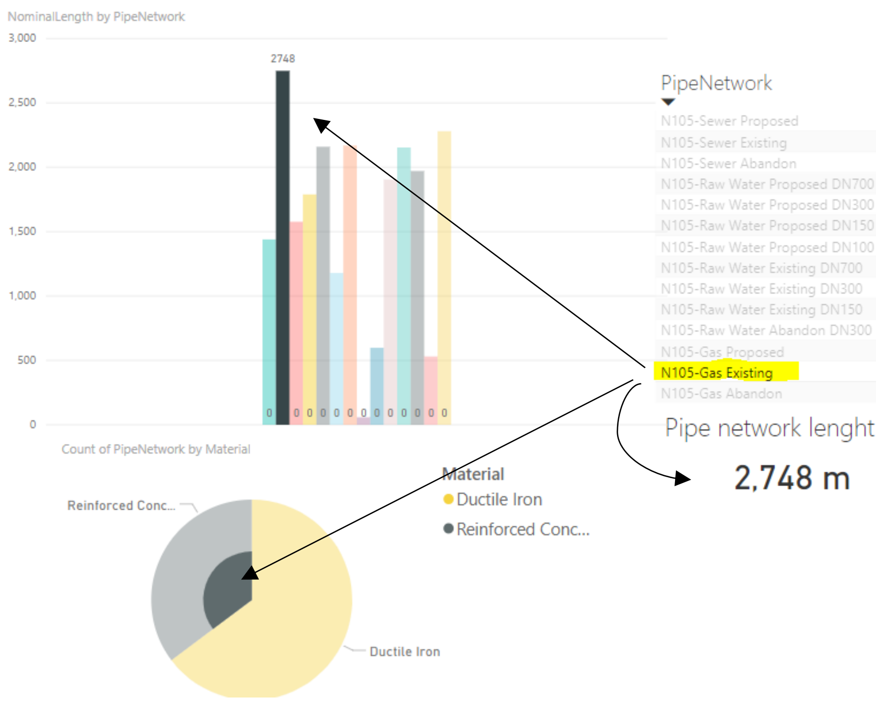


Figure 44 - Project overview dashboard interactions (Power BI)

The second dashboard of the project is called *"The main dashboard"*. The content of the board is the following:

- a card, which shows the date – parameter;
- a simple Gantt chart from the table created during the data modelling phase ("*ProjectCompletionTable*");
- Clustered bar chart, where I put the percentage of planned and actual completion as values; the advantage of this chart is that it allows to add and visualize two values at the same time;
- A clustered column chart, with actual and planned costs as added values. As well as a clustered bar chart, it allows to add more than one value to the same chart and hence to better visualize the differences;
- Several cards showing the percentage of completion and costs changes.

The overall dashboard is shown below (figure 45):

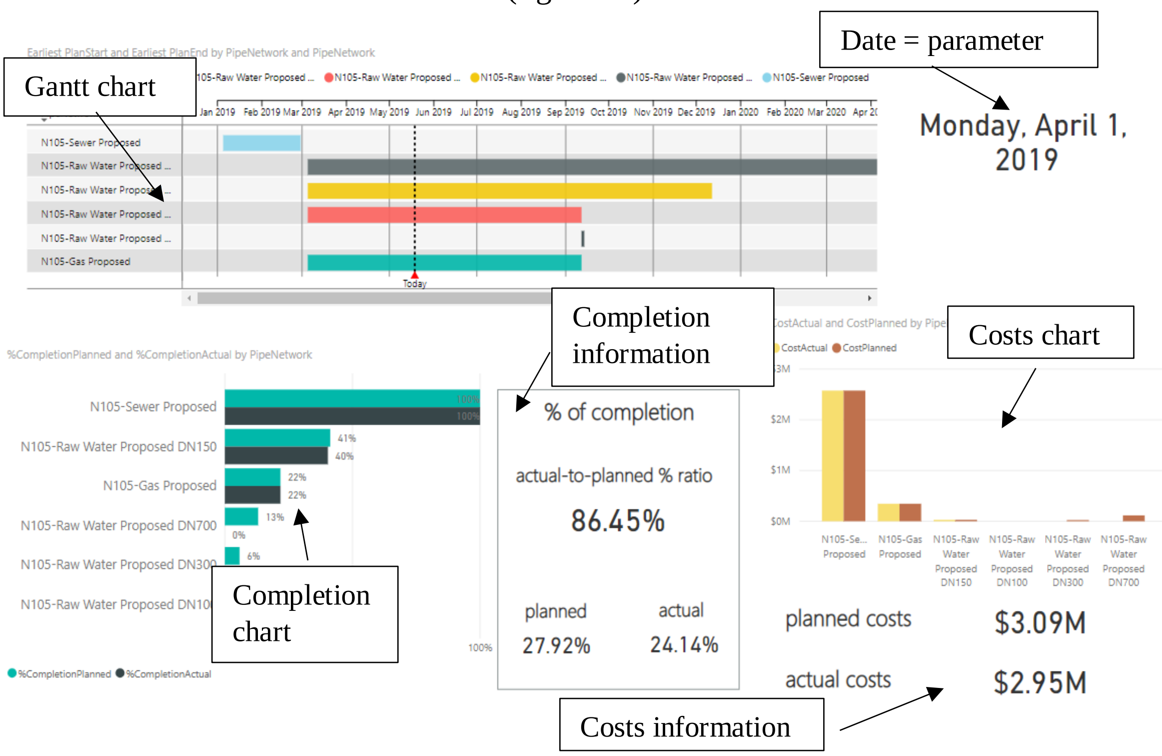


Figure 45 - Main project dashboard (Power BI)

On the top, there is a visual called Gantt Chart (figure 46). Gantt chart represents a simple orientation planned schedule of each proposed pipe network. The indicator in the schedule always shows the actual date.

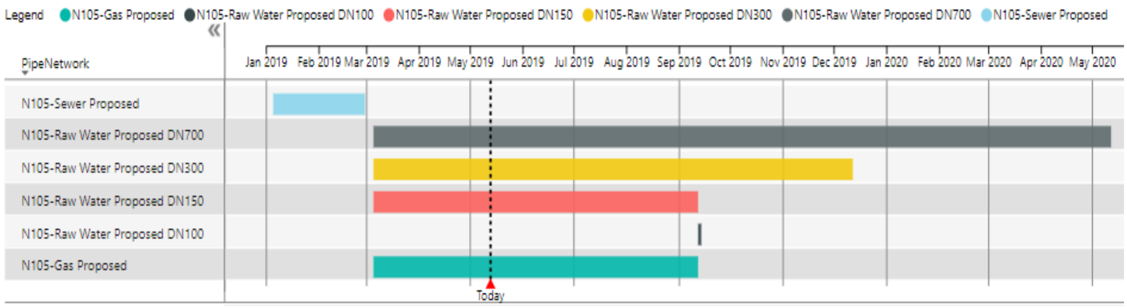


Figure 46 - Gantt Chart (Power BI)

On the next chart there is a percentage of completion shown for each network (figure 47). Up to the February 1 of 2019, there was only sewer started:

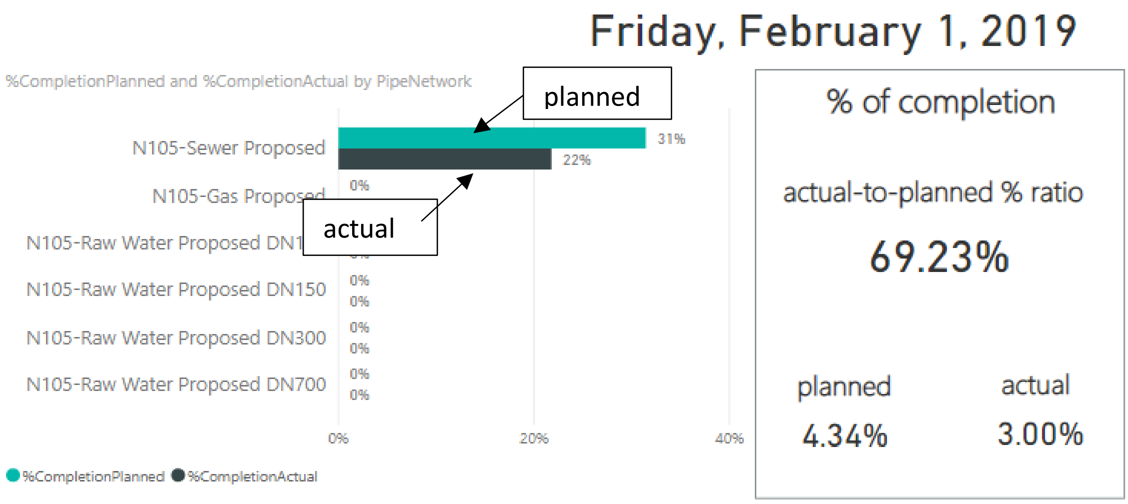


Figure 47 - Clustered bar chart (Power BI)

However, if one will change the date, the chart will change accordingly. Unfortunately, there is no method in Power BI to change it by the user input directly from the dashboard at the moment. To choose another date is possible through editing the parameter(figure 48):

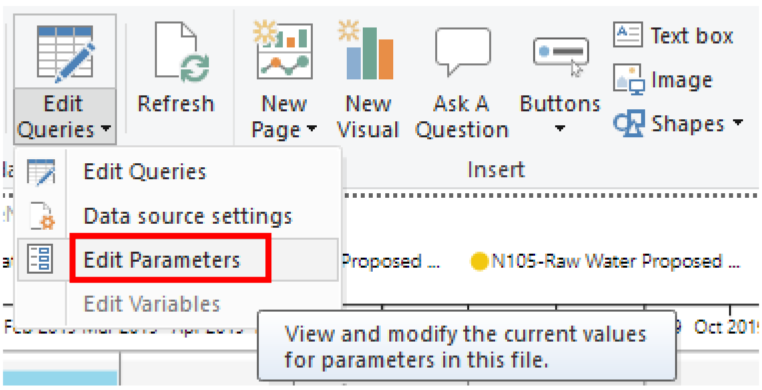


Figure 48 - Editing the parameter (Power BI)

The list of dates which I was creating as part of the data preparation stage will drop down so the needed date can be selected (figure 49):

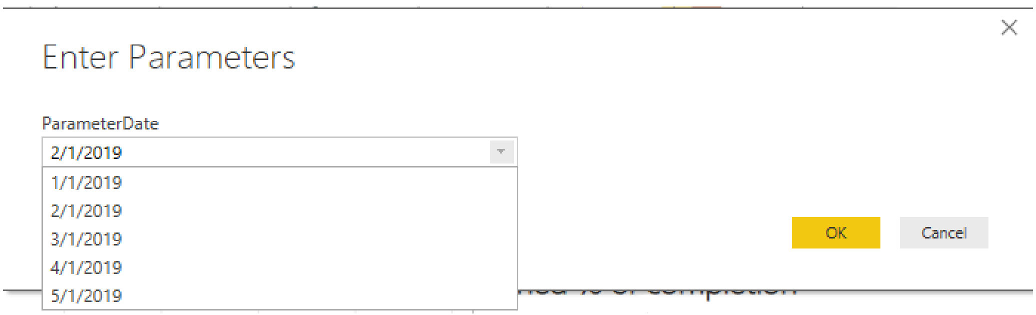


Figure 49 - Parameter's drop-down (Power BI)

Now, after I have selected a different date and applied changes, the clustered bar chard has changed and shows the completion up to April 1 of 2019, which is shown in figure 50:

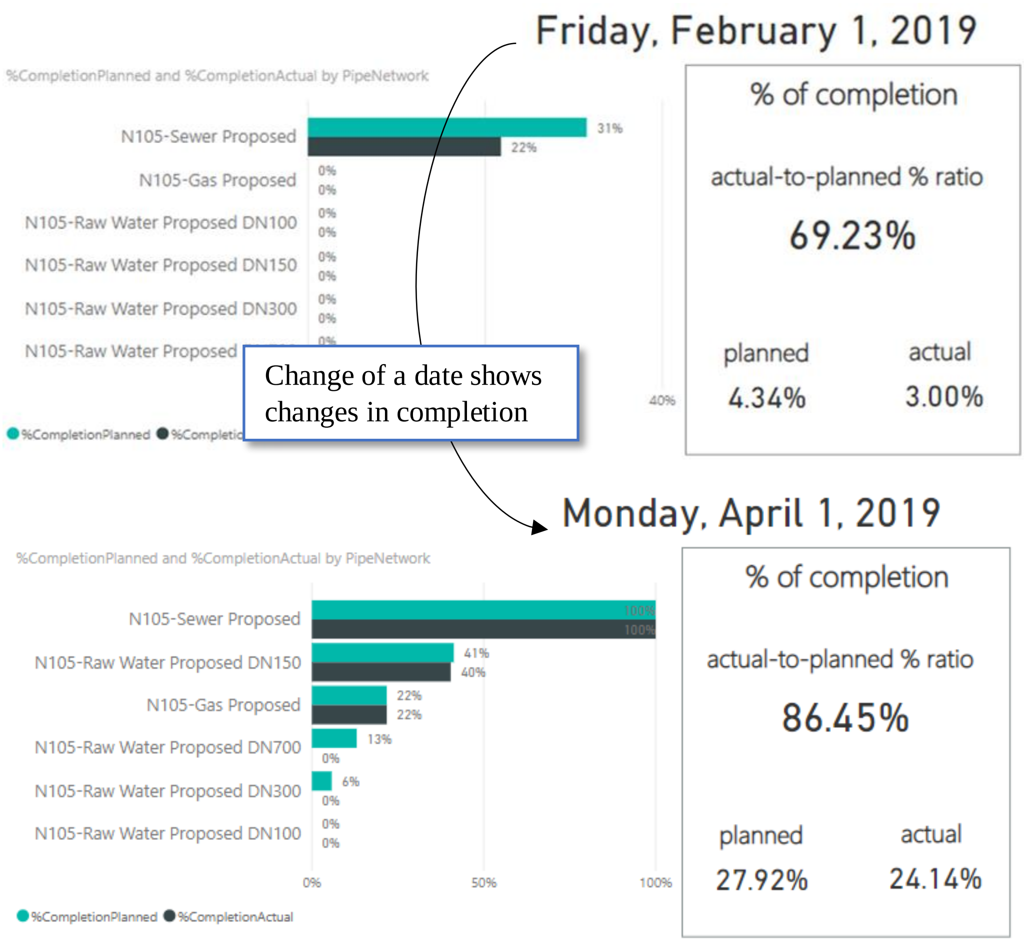


Figure 50– Completion chart (Power BI)

The next important chart represents costs of the project – according to planned expenditures and according to actual. Same as completion, it changes with every month passed (figure 51).

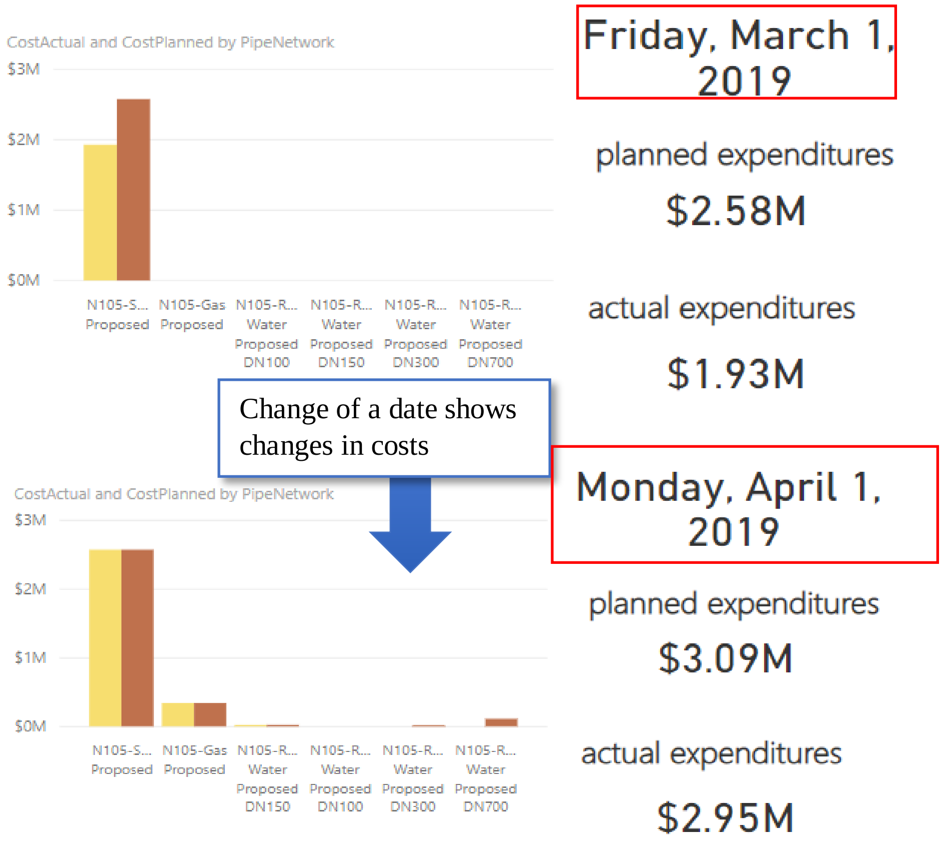


Figure 51 - Costs chart (Power BI)

The user can interact with the chart on the dashboard thanks to all the relationships within the database (figure 52). The dashboards are therefore dynamic.

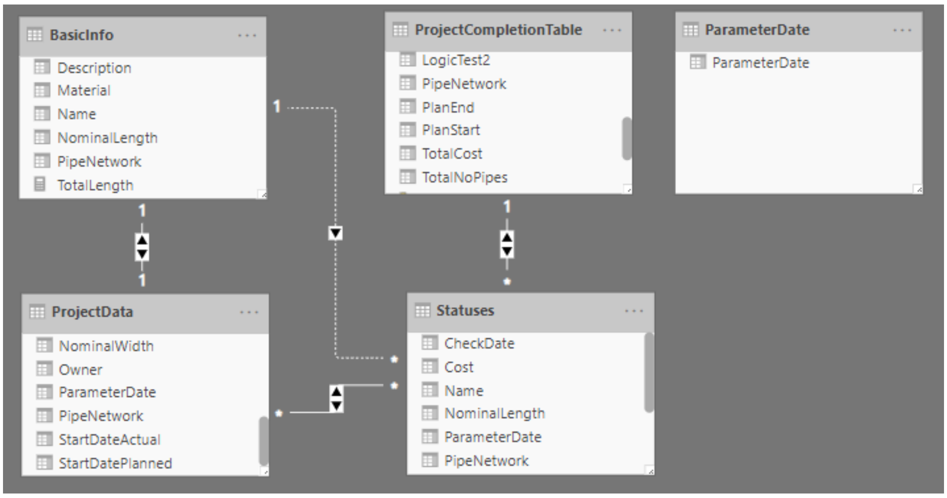


Figure 52 - Data relationships (Power BI)

In figure 53 below there is an example of how relationships work. When the user presses any entity on one of the charts, in this case N105 Raw Water Proposed DN150, it highlights the relevant data, the others are faded. Gantt Chart is changed – now it is showing only schedule for the chosen pipe network. The costs are changed as well, according to what is relating to the chosen pipe network.

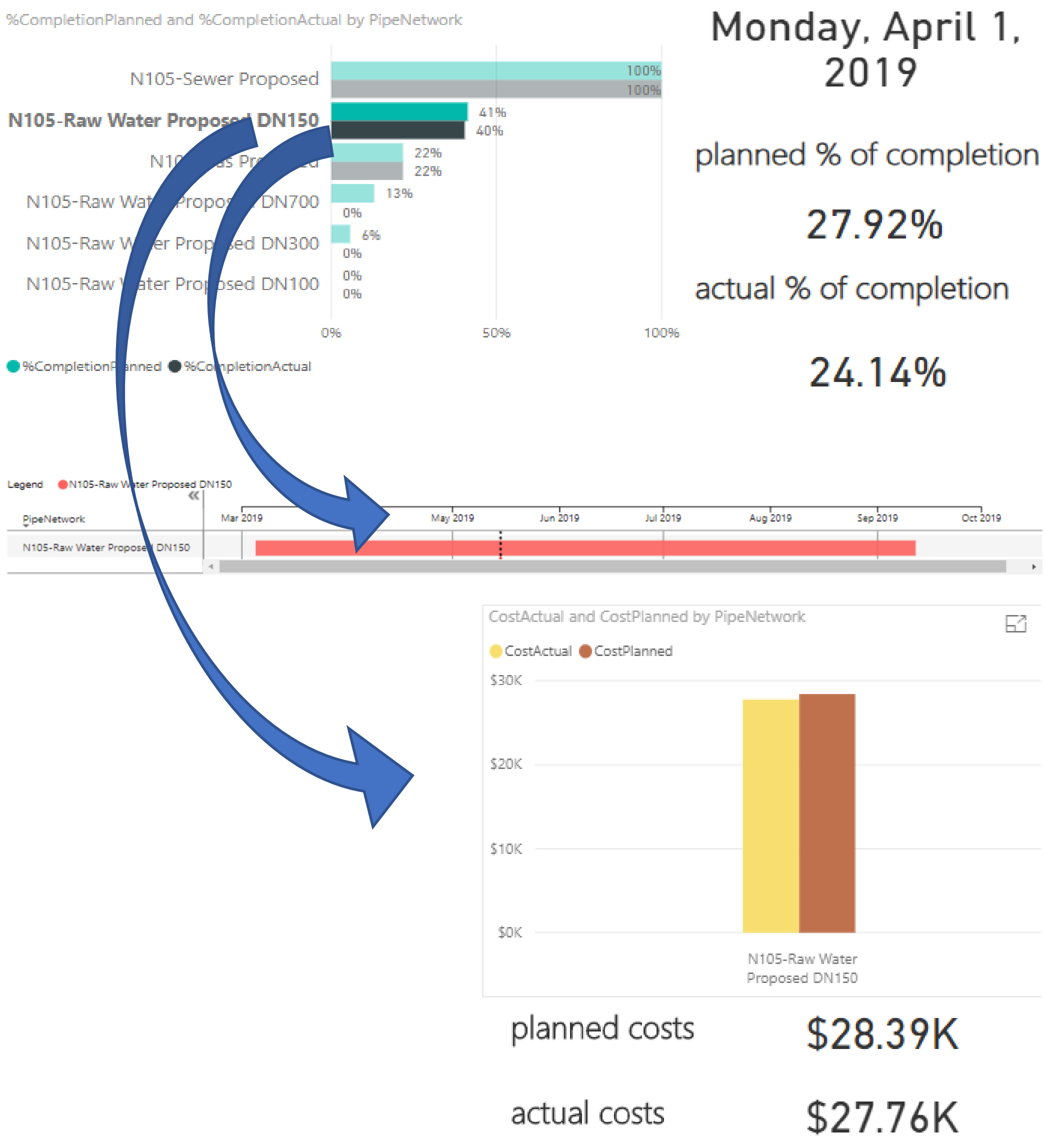


Figure 53 - An example of values' changing (Power BI)

The third dashboard is called “Statuses” and it contains the information about suitability codes. There are such visualizations as:

- A card with the date – parameter;

- Pie chart, which represents all statuses in relevant proportions;
- Clustered chart, which shows the costs equivalent for each pie chart proportion;
- Clustered chart showing the amount of statuses for the relevant months;
- Clustered chart showing the correlation between status and the network length;
- A table with pipe network name, costs and length for better structuring and information.

The overall dashboard is shown below (figure 54):

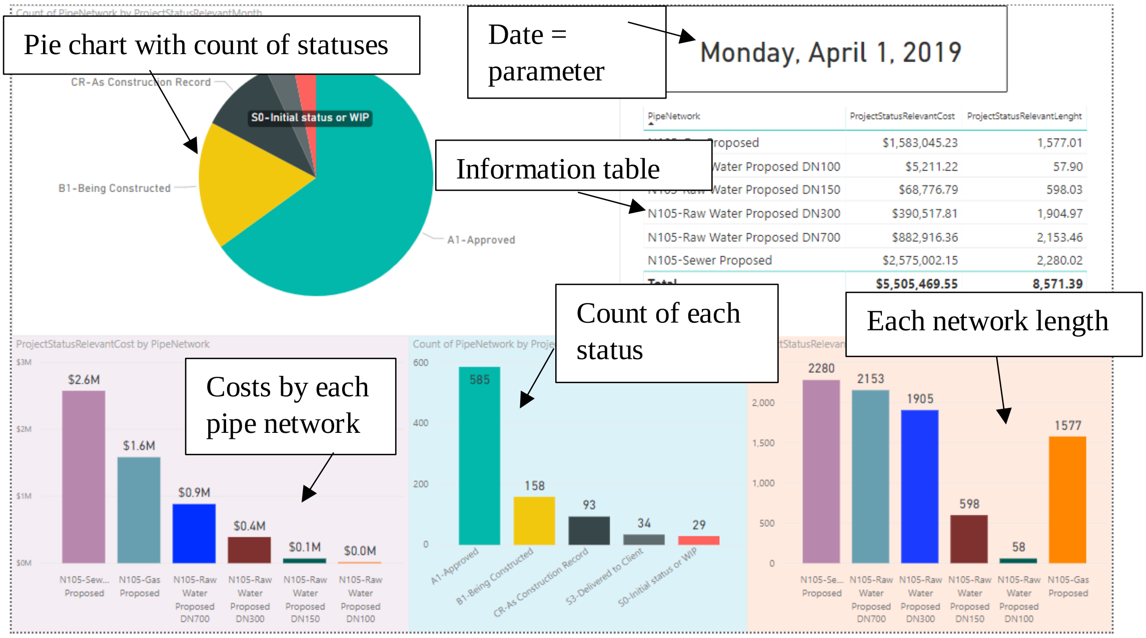


Figure 54 - Suitability Codes dashboard (Power BI)

The suitability codes (which were described in part *3.7.2 Suitability Codes*) are used in this work for showing the status of each pipe, so it is possible to track the changes and control if everything is going according to the schedule. The status change might show the efficiency and signalize a possible stoppage or possible problems. As in previous dashboards, the data are interacting with each other in a dynamic way and changing relevantly according to the chosen date parameter.

On the example below, the chart shows the count of codes up to April 1,2019 (figure 55). I have chosen one suitability code for demonstration – *A1-Approved* (figure 56).

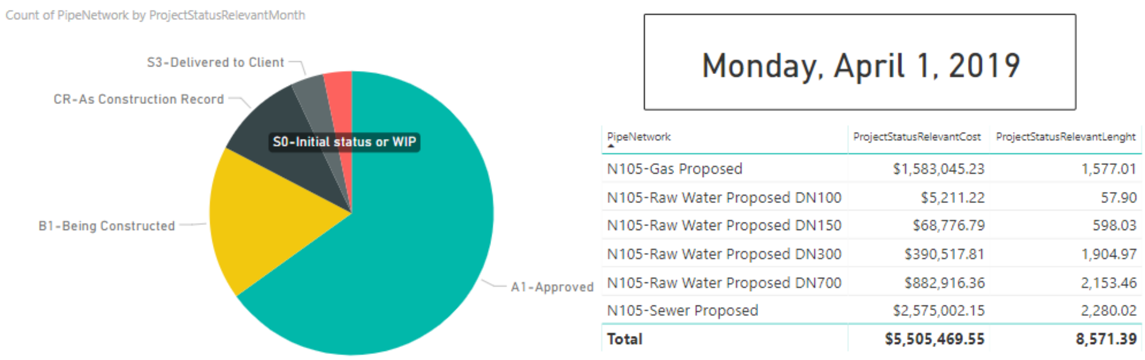


Figure 55 – Suitability Codes state by April 1,2019 (Power BI)

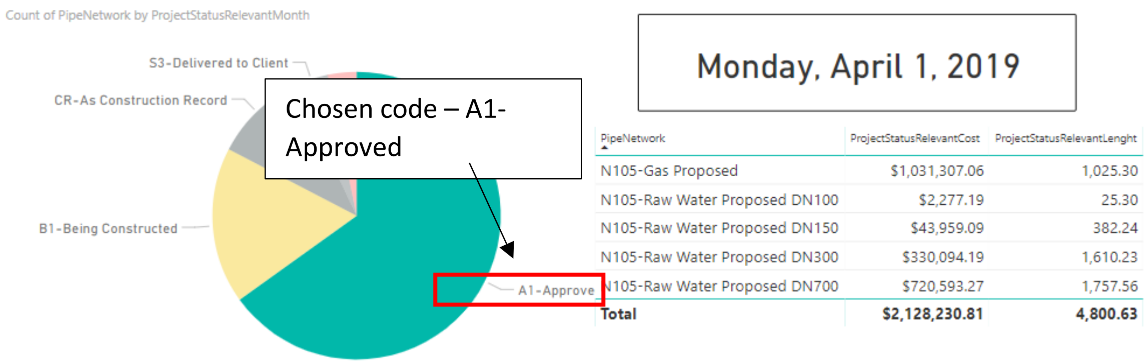


Figure 56 – A1-Approved Suitability Code chosen (Power BI)

When chosen, the corresponding data is highlighted. The table on the right now contains different data in figure 56. The bar charts below are also showing the corresponding data.

Costs chart was changed according to *A1-Approved* status and is showing how much costs in each pipe network have *A1-Approved* status (figure 57). The total sum can be seen on the table in figure 56.

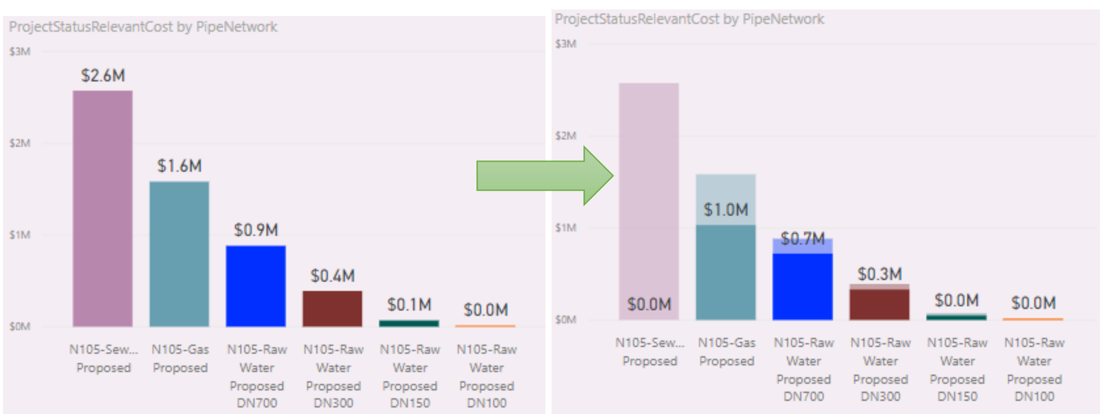


Figure 57 – Cost chart before and after choosing A1-Approver Suitability Code (Power BI)

The next bar in figure 58 chart represents the count of each Suitability Code. The sum, therefore, would show the total number of pipes in the project. When *A1-Approved* status is chosen, the chart will only highlight the appropriate bar, because this chart already contains statuses only for chosen month.

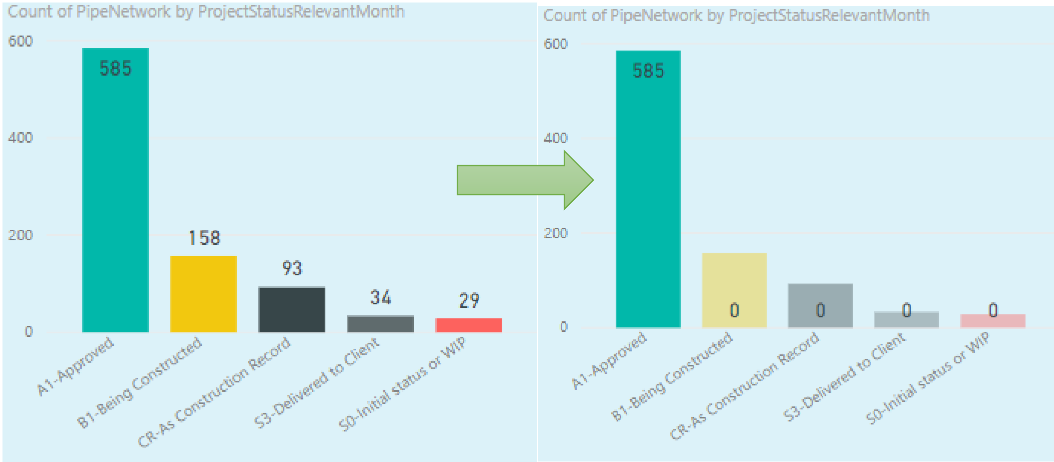


Figure 58 – Statuses chart before and after choosing A1-Approver Suitability Code (Power BI)

The last chart in figure 59 shows each pipe network length and how it is reflecting the chosen *A1-Approved* status. It can be seen, for example, that for April 1 of 2019, 1758m out of 2153m of Raw Water Proposed DN700 network contains A1 status.

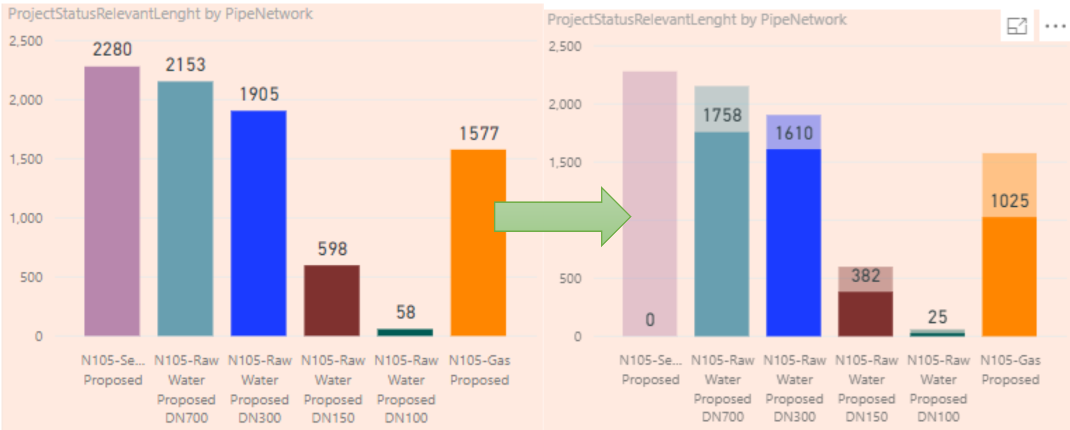


Figure 59 - Lengths chart before and after choosing A1-Approver Suitability Code (Power BI)

4. Conclusion

In the last part of the thesis I would like to share the conclusions I came to while working on this project. I was exploring the proposed workflow which I developed in a way which enables data creation and data transfer from a BIM authoring software to the Power BI analytics service in order to achieve greater visibility and better decision-making. The workflow was validated on the infrastructure project with a mix between real and simulated data.

The process requires quite a lot of manual work: it is needed to constantly update data, whether it is every day, week or month (or otherwise depending on the agreement). One can be required to update the data in a BIM model software and then it is necessary to repeat the whole process up to the Excel spreadsheet stage. The latter is linked to Power BI and to complete the process one has to press a refresh button in Power BI to transfer all newly updated data. In a simpler version of the process, data can be updated directly in an Excel file. However, this way is not as straightforward as the previous as the Excel file contains many spreadsheets with thousands of lines.

The whole process needs to be discussed with all involved project parties before the project commencement, so that they have a clear understanding of what they should focus on and at what stage the data is required to be transferred to another party – e.g. from subcontractor to the general contractor.

I used the data simulation for the construction stage of the project, however, data for asset management can also be added into Power BI for better facility management and assets maintenance. Visualised maintenance data would provide easier orientation and tracking rather than standard COBie spreadsheet.

The main advantage that this workflow brings, is a great overview and knowledge about data for the Project Manager, that one could not have before. Thanks to the greater visibility and data tracking, Power BI is enabling to control project costs, schedule and completion, to anticipate potential problems, reduce risks and apply appropriate actions. In the end, as far as I am concerned, it would definitely be worth going beyond simulation and applying the process to the case.

List of references

ASHWORTH, Simon and Matthew TUCKER. *Employer's information requirements (EIR). Template and Guidance: Facilities management and client operating requirements in the Building Information Modelling (BIM) process*. The UK: The British Institute of Facilities Management, 2017. ISBN 978-1-909761-27-8.

AUTODESK INC. *AutoCAD* [software]. Available: https://www.autodesk.com/products/autocad/overview

AUTODESK, INC. Autodesk Navisworks 2017 Solutions [online]. [cited 2019-04-01]. Available: https://knowledge.autodesk.com/sites/default/files/Navisworks%202017%20-%20Supported%20Formats%20and%20Applications_V3.1.pdf

AUTODESK INC. *Autodesk Navisworks Manage 2018* [software]. Available: https://www.autodesk.com/products/navisworks/overview

AUTODESK INC. *COBie Extension for Navisworks* [software extension]. Available: https://www.biminteroperabilitytools.com/cobieextensionnavis.php

Building in Cloud [online]. [cited 2019-05-16]. Available: https://www.buildingincloud.net/en/bim-collaboration-2/

BuildingSMART. IFC Technology [online]. [cited 2019-03-17]. Available: http://www.buildingsmart-tech.org/specifications/ifc-overview/ifc-technology

BuildingSMART. Industry Foundation Classes [online]. [cited 2019-03-17]. Available: http://www.buildingsmart-tech.org/ifc/

COMPUTER INTEGRATED CONSTRUCTION RESEARCH PROGRAM. (2011). *BIM Project Execution Planning Guide – Version 2.1*. The Pennsylvania State University, University Park, PA, USA.

CONSTRUCTION PRODUCTS ASSOCIATION and NBS. *BIM for the terrified. A guide for manufacturers*. The UK, 2013. ISBN 978-1-909415-03-4.

EAST, E. William (2012) *Construction-Operations Building information exchange (COBie)*, buildingSMART alliance, National Institute of building Sciences, Washington, DC. [cited 2019-04-25]. Available: http://www.nibs.org/?page=bsa_cobie

EASTMAN, Charles M. *BIM handbook: a guide to building information modelling for owners, managers, designers, engineers and contractors*. 2nd ed. Hoboken, NJ: Wiley, 2011. ISBN 978-0-470-54137-1.

EDUCBA. Power BI vs Excel [online]. [cited 2019-04-01]. Available: https://www.educba.com/power-bi-vs-excel/

KUMAR, Bimal. *A practical guide to adopting BIM in construction projects*. Dunbeath: Whittles Publishing, 2015. ISBN 978-184995-146-3.

LAND TRANSPORT AUTHORITY. North-South Corridor [online]. 2018 [cited 2019-04-05]. Available: https://www.lta.gov.sg/content/ltaweb/en/roads-and-motoring/projects/north-south-corridor.html

LAND TRANSPORT AUTHORITY. LTA Awards Contract for North-South Corridor Tunnel between Suffolk Walk and Novena Rise [online]. 2018 [cited 2019-04-05]. Available: https://www.lta.gov.sg/data/apps/news/press/2018/20180731_NSC_tunnel_loc_map_AnnexA.pdf

LAND TRANSPORT AUTHORITY. LTA Awards Contract for North-South Corridor Tunnel between Suffolk Walk and Novena Rise [online]. 2018 [cited 2019-04-05]. Available: https://www.lta.gov.sg/data/apps/news/press/2018/20180731_NSC_alignment_loc_map%20_AnnexB.pdf

LORENZ, Manuel. *Microsoft Power BI - A Complete Introduction* [video], 2019. [cited 2019-04-01]. Available: https://www.udemy.com/powerbi-complete-introduction/

MCPARTLAND, Richard. *BIM dimensions - 3D, 4D, 5D, 6D BIM explained* [online]. 2017 [cited 2019-03-22]. Available: https://www.thenbs.com/knowledge/bim-dimensions-3d-4d-5d-6d-bim-explained

MICROSOFT CORPORATION. *Power BI* [online]. [cited 2019-04-25]. Available: https://powerbi.microsoft.com/en-us/

MICROSOFT CORPORATION. *Power BI Desktop* [software]. Available: https://powerbi.microsoft.com/en-us/

MINISTRY OF INDUSTRY AND TRADE. *Koncepce zavádění metody BIM v České republice* [online]. Czech Republic, 2017 [cit. 2019-04-17]. Available: https://www.mpo.cz/assets/cz/stavebnictvi-a-suroviny/bim/2017/10/Koncepce-zavadeni-metody-BIM-v-CR.pdf

NATIONAL BUILDING SPECIFICATION. The IFC/COBie Report 2012 [online]. [cited 2019-03-20].

NATIONAL INSTITUTE OF BUILDING SCIENCES. *Frequently asked questions about the National BIM Standard – United States* [online]. [cit. 2019-04-18]. Available: https://nationalbimstandard.org/faqs

NATIONAL INSTITUTE OF BUILDING SCIENCES. *National Institute of Building Sciences: National BIM standard - United States* [online]. [cited 2019-03-15]. Available: https://www.nationalbimstandard.org/

PENN STATE COMPUTER INTEGRATED CONSTRUCTION RESEARCH GROUP. *BIM Uses* [online]. [cited 2019-03-19]. Available: https://www.bim.psu.edu/bim_uses/

ROYAL INSTITUTE OF BRITISH ARCHITECTS. *BIM Overlay to the RIBA Outline Plan of Work* [online]. RIBA Publishing, 2012 [cit. 2019-02-10]. ISBN 978-1-85946-467-0. Available: https://www.architecture.com/-/media/gathercontent/riba-plan-of-work/additional-documents/bimoverlaytotheribaoutlineplanofworkpdf.pdf

THE BIM DICTIONARY TEAM. *BIM Dictionary* [online]. [cited 2019-03-16]. Available: https://bimdictionary.com/en/common-data-environment/1/

THE BIM DICTIONARY TEAM. *BIM Dictionary* [online]. [cited 2019-03-16]. Available: https://bimdictionary.com/en/cobie/1/

THE BRITISH STANDARDS INSTITUTION 2019. *BS EN ISO 19650-1:2018: Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Information management using building information modelling. Part 1: Concepts and principles*. The UK, 2019. ISBN 978-0-580-92466-8.

THE BRITISH STANDARDS INSTITUTION 2019. *BS EN ISO 19650-1:2018: Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Information management using building information modelling. Part 2: Delivery phase of the assets*. The UK, 2019. ISBN 978-0-580-92467-5.

THE BRITISH STANDARDS INSTITUTION. *PAS 1192-2:2013: Specification for information management for the capital/delivery phase of construction projects using building information modelling*. The UK: BSI Standards Limited, 2013. ISBN 978-0-580-82666-5.

THE BRITISH STANDARDS INSTITUTION. *PAS 1192-3:2014: Specification for information management for the operational phase of assets using building information modelling*. The UK: BSI Standards Limited, 2014. ISBN 978-0-580-86674-6.

THE BRITISH STANDARDS INSTITUTION. *BS 1192:2007+A2:2016. BRITISH STANDARD: Collaborative production of architectural, engineering and construction information – Code of practice*. The UK: BSI Standards Limited, 2016. ISBN 978-0-580-92817-8.

THE BRITISH STANDARDS INSTITUTION. *BS 1192-4:2014: Collaborative production of information. Part 4: Fulfilling employer's information exchange requirements using COBie – Code of practice*. The UK: BSI Standards Limited, 2014. ISBN 978-0-580-85255-8.

THE STATE FUND FOR TRANSPORT INFRASTRUCTURE and MINISTRY OF INDUSTRY AND TRADE OF THE CZECH REPUBLIC. *Analýza užití informačního modelování staveb (BIM) pro infrastrukturní stavby*. 2018.

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