Univerza *v Ljubljani*
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in geodezijo

MAHYA NAZARI

MINIMUM DATASETS FOR 4D SIMULATION OF INFRASTRUCTURE PROJECTS AND THEIR CARBON FOOTPRINT

MASTER THESIS

SECOND CYCLE MASTER STUDY PROGRAMME BUILDING INFORMATION MODELLING – BIM A+

Ljubljana, 2021

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MINIMUM DATASETS FOR 4D SIMULATION OF INFRASTRUCTURE PROJECTS AND THEIR CARBON FOOTPRINT

MINIMALNI PODATKI ZA 4D SIMULACIJO INFRASTRUKTURNIH PROJEKTOV IN NJIHOVEGA ODTISA CO2

European Master in
Building Information Modelling

Master thesis No.:

Supervisor:
AProf. Tomo CEROVŠEK, Ph.D.

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Avtor: **Mahya NAZARI**

Mentor: **AProf. Dr. Tomo CEROVŠEK, Ph.D.**

Somentor: **Marko ANDREJAŠIČ, univ. dipl. inž. grad.**

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Izvleček:

Hitra rast infrastrukturnih projektov, kot so tuneli, povzročajo potrebo po digitalizaciji v tem sektorju. V zadnjem času je informacijsko modeliranje zgradb vse pogostejše na področju infrastrukture, za lažjo gradnje pa se uporabljajo različni vidiki BIM, na primer 4D BIM.

Čeprav so številna raziskovalna dela obravnavala raznotere vidike BIM na različnih področjih, ni celovitega ogrodja, ki bi inženirjem pomagal določiti, kateri podatki so bistveni za terminsko planiranje infrastrukture. Statistični podatki kažejo, da je terminsko planiranje zaradi velike količine podatkov pogosto dolgotrajno in neurejeno. Poleg tega je gradnja in prenova železniške infrastrukture znana kot eden od večjih virov ogljičnega odtisa CO2. Zato ima lahko iskanje ustreznega vizualnega in praktičnega načina simulacije emisij CO2 v odvisnosti od časa zelo pomembno vlogo v gradbeni industriji.

Zaradi navedenega ta študija obravnava pripravo minimalno potrebnih podatkov za izdelavo modela 4D z ogljičnim odtisom, ki bi lahko vodila do znatnega zmanjšanja količin CO2. Ker BIM lahko nudi ključen input za aplikacije VR (virtualno resničnost), se metodologija opira na 4D modeliranje, vključno z uporabo navidezne resničnosti in nadgrajeno s podatki o ogljičnem odtisu, ki omogoča VR presojo vplivov projektov železniške infrastrukture na okolje v odvisnosti od časa.

Pristop smo demonstrirali na prktičnem primeru železniškega projekta, za katerega smo pridobili model BIM in posnetek v obliki oblakov točk, kar smo nadgradili s simulacijo 4D in ogljičnim odtisom CO2. Ogrodje je uporabno za upravljanje BIM pri infrastrukturnih projektov in presoji vplivov na okolje

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BIBLIOGRAPHIC– DOKUMENTALISTIC INFORMATION AND ABSTRACT

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Author: **Mahya NAZARI**

Mentor: **AProf. Tomo CEROVŠEK, Ph.D.**

Co-Mentor: **Marko ANDREJAŠIČ**

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Abstract:

Rapid growth in infrastructure projects such as tunneling cause rising the demand of digitalization in this sector. Recently, building information modeling has become more common in the infrastructure field and different aspects of BIM such as 4D BIM have been used to facilitate construction.

While many research works have addressed various aspects of BIM in different fields, there is no comprehensive framework that can help engineers to know which data is essential for infrastructural scheduling. Statistic shows, due to the vast amount of data, scheduling can be time taking and confusing. Moreover, constructing and refurbishing railway infrastructure projects is known as one of the critical sources of carbon footprint emissions. Hence, finding a visual and practical way for simulating carbon emissions over time could play a vital role in the construction industry.

Therefore, this study identifies the minimum data sets required for the development of a 4D model with a carbon footprint that could lead to a decrease in the amount of carbon emission. As BIM can provide key input for the virtual reality (VR) applications, the methodology develops an approach for 4D modeling scheduling using BIM, which is enhanced with carbon footprint data, that allows for VR assessment of the impact of a particular railway infrastructure project on the environment over time.

The approach has been demonstrated in a practical case study of a railway project for which a BIM model and point cloud was made available and upgraded with 4D and CO2 footprint. The framework is useful for BIM management of railway infrastructure projects and its impact on the environment.

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1 INTRODUCTION

1.1 Thesis Context

Humans are attempting to adopt novel solutions to the problem of global warming. Global warming is a rapidly developing phenomenon caused by increased carbon emissions in the environment. Carbon emissions come from a variety of sources, with construction being one of the most significant. Various strategies have been developed to reduce the amount of carbon pollution created in the building industry, with BIM emerging as the most effective in recent years. By analyzing all aspects of a project's performance, such as materials, energy efficiency, and other factors, BIM can save waste and enhance construction quality. For example, Martins and his colleague proved controlling used materials in pre-construction stage and monitor it through 4D and visually can improve energy efficiency of the buildings (Martins et al., 2020). Najjar and Evangelista also showed that monitoring projects, particularly in the early design stage, can minimize the environmental impact through minimizing the weight and quantities of construction components (Najjar, Figueiredo, Evangelista, et al. 2019). Although sustainability is a key factor for planning infrastructure projects and is highly beneficial for establishing a framework for measuring environmental impact, statistics show that the development of sustainable infrastructure rating systems has been relatively slow for this sector (McVoy et al., 2010), and there is still a large gap in terms of using BIM to create sustainable design in this sector.

On the other hand, traditionally, client and contractor used two-dimensional (2D) paper-based drawing to provide planning which was really time consuming and confusing. Doing so often leads to the collection of data between 2D and 3D models, which can cause misunderstandings and errors. Also, it can be challenging for non-professionals to understand 2D-drawings. For Planning also, contractors used traditional methods such as Critical Path Method (CPM) or network diagrams that were similar to 2D, this way of scheduling was inefficient. Due to the increasing number of projects that were delayed due to poor planning and scheduling.(Shah et al., 2008)(Dawood et al., 2009), the advantage of IT has increased significantly. One of the greatest innovations in this field was 4D planning. This process links a 3D model with time and component information. This technology allows engineers to add various components to a project. All of the authors have provided insights and evaluations of current practice and research directions in 4D BIM in recent years. However, there is one area that is not sufficiently investigated, despite the fact that it might aid in improving the planning design process and the total construction project.

The data collected during the construction of a project is an essential part of the process and during the transmission of the data, the necessary steps should be taken. Furtheremore, data is becoming increasingly crucial in today's world. As a result, storing data accurately and accessing it precisely are critical concerns. For creating 4D planning, various sorts of data should be integrated. The physical parameters of real objects, such as width, length, and depth/height, are currently stored in most databases using a three-dimensional (3D) data format. Time and Tasks also are known as another source of data. The obstacles of creating 4D BIM models are related to precise data and geometry, as well as how they are tied to the timetable. Therefore, the value of knowing about the essential data for creating 4D is becoming more important as interest in collaborative 4D BIM modeling and simulation grows.

1.2 Problem Statement

As a result of increasing interest in using 4D BIM, the importance of tackling to its limitations has enhanced. While many research works have addressed various aspects of BIM in different fields, there is no comprehensive framework to help engineers to know which data is essential for infrastructural scheduling. Statistic shows, due to the vast amount of data, scheduling can be time taking and confusing. Furthermore, any changes to task duration, lags and relationship between tasks will result in a new project schedule. Additionally, in recent years, advances in technologies such as the internet of things (IOT) is accelerating data explosion. Otherwise, as scheduling before starting projects, can play a vital role in decreasing the cost of construction, it is essential to find a suitable way to create it.

On the other hand, In today's world, reducing carbon footprint as well as greenhouse gas emissions and preventing its disastrous effects on climate has become a global goal. Constructing and refurbishment of railways as an infrastructure project is known as one of the carbon emission sources. By examining current literature and case studies, Olugbenga and his colleagues calculated that 941(168) tCO2e are embodied per kilometer of rail at-grade, and tunneling has 27 (5) times more embodied GHG per kilometer than at-grade construction (Olugbenga et al., 2019). It has also been established that infrastructure renewal, construction, and maintenance activities are responsible for about 20% of CO2 emissions from all railway services combined. (Hill et al., 2011). Furthermore, due to the increase of population and considering railways as a green kind of transportation system, the construction of railways and maintenance of the existing ones has increased rapidly and it has become a source of carbon footprint emission. In fact, although railways are known as an environmentally friendly transportation system, its carbon emission during construction and especially refurbishment of the existing ones should be calculated accurately. Statistics show, among all resources that creat carbon-footprint, concrete is the main one that create too much carbon emission. Also, When comparing similar, optimal structures made of steel, wood, and concrete, concrete structures emit the most greenhouse gases (Maas, 2011).

Therefore, finding a visual and practical way for simulating carbon emission of concrete resources and 4D scheduling can play a vital role in the construction industry. Traditional planning of the projects and calculating the carbon footprint was paper-based and manually. By advancing in technology, different ways such as using 4D planning have become more and more common. While using these technologies can be highly beneficial, it is not exactly obvious how much data is needed to calculate and do the planning. For proper planning, however, identification of the essential data plays a significant role during the all stages of a project.

Using 4D BIM is known as one of the existing ways for waste management and life cycle assessment. Zhou and Wang developed a four-dimensional simulation model for bridge construction management, demonstrating that using four-dimensional simulation for bridges reduces resource waste (Zhou and Wang, 2009). It was also shown that management actions such as operating frequency have a significant impact on carbon footprint (Choi, 2019). While working with 4D can be helpful to reduce energy consumption, there is no comprehensive framework to help engineers to know how 4D-scheduling can help to minimize carbon emission and is there any way to calculate the produced Carbon footprint of concrete resources via 4D BIM while using the minimum amount of data. Achieving the minimum data can and implementing open data principle can be highly beneficial for academia, private sectors and specialists.

1.3 Purpose and Research questions

Many academics have recently begun to apply Building Information Management (BIM) to other fields, such as sustainability. It has been demonstrated that BIM, as a cutting-edge technology, can play a critical role in lowering carbon emissions. According to research, one of the most crucial parts of a construction is effective planning (Chevallier and Russell, 1998) With the use of 4D-BIM simulations can significantly enhance construction management and decrease waste by eliminating rework during the project. Furthermore, in recent years, due to the importance of civil infrastructure projects regarding their capital investment, BIM technologies are gradually moving from the world of architecture to the infrastructure areas to integrate all the information and data analysis. Due to the increasing the population, the speed of construction and refurbishment of transportation systems such as railways and tunneling have been raised dramatically recently.

Therefore, The main goal of this research is an approach for collecting and visualizing minimum data for 4D BIM enabled embodied carbon footprint producing via concrete resources and finding an integrated method to manage the carbon emission at the preconstruction stage of a railway tunneling. VR application is used to visualize any schedule changes in order to find minimum required data directly through the VR model. Other purpose of the study are as following:

1- Reducing the data used for scheduling of the infrastructure by controlling it via VR (Due to the fact that virtual environments offer unique situations enabling users to experience the real environment).

2- Identifying and collecting data needed to determine the carbon footprint of railway infrastructure.

In the study, it was tried to find an answer to these questions:

- How much data is essential to create 4D scheduling and calculating carbon footprint?

- Can we reduce the amount of carbon footprint in railway infrastructure projects via optimizing construction by 4Dsheduling and checking it through Virtual Reality (VR)?

- Can 4D scheduling be a suitable method of assessment of CO2 emission from concrete production?

The accompanying the study some sub-question also will be answered such as:

- What special data and information are needed for creating 4D scheduling?

- Is 4D scheduling the suitable way for controlling the carbon emission?

1.4 Methodology and Limitations

1.4.1 Research design

The research design is the unique way of collecting, analysing and discussing datas to link research to the research problem. Exploratory and Conclusive are the two groups of this general idea.

Exploratory and Conclusive Research method

In this strategy, research is used to gather knowledge in order to better understand the problem; it does not result in a specific outcome.

In fact, academics can only gain a greater understanding of the subject via this methods.

Qualitative and Quantitative Research Method

Mixed method research combines qualitative and quantitative research methods. This methodology was characterized as a process that collects and analyzes both qualitative and quantitative data in simultaneously (Kemper et al., 2003).

1.4.2 Research Method Adopted

In this study two combinations of two methods, quantitative and qualitative are employed. Since the collaboration of 4D models and VR environments for various purposes have been proved recently (Ku, Mahabaleshwarker, 2011), (Sampaio, Martins, 2014), (Cruz, 2018), for overcoming the limitations and having a unique and real visualization during the research for achieving the minimum data, Virtual reality (VR) as a decision-making tool will be used. This study, therefore, aims to improve 4D scheduling and calculating carbon footprint in infrastructure projects by using BIM and innovation technologies.

1.4.3 Case study

A case study is developed in association with Geoportal (Slovenia). For achieving the data, the 4D scheduling and carbon emission of the concrete used in the refurbishment of double-track Karawanken railway tunnel is done. As it can be seen in the literature review, most studies have been done in different sorts of infrastructure such as roads, highways and bridges and there is not comprehensive study about tunneling.

1.4.4 Data collection Method

The data for the study was gathered from a variety of research and servey sources. During the data collection process, the data collection's reliability and validity was double-checked. A range of documented material such as academic publications, written articles, websites and industry organizations reports have been checked to collect essential data.

1.4.5 Research design

The study is done through these following steps:

- Creating 3D model
- Collecting data (creating work breakdown, estimate activities duration, define activities sequences and their relationship, Allowing resources for each activity)
- Calculating carbon footprint for concrete resource
- Linking tasks and related amount of carbon Footprint of resources to 3D-model to create 4D
- Checking 4D scheduling to remove all clashes.

- Checking the 4D model through VR to know the amount of data is enough for evaluation
- Calculating carbon footprint concrete resources on 4D simulation.

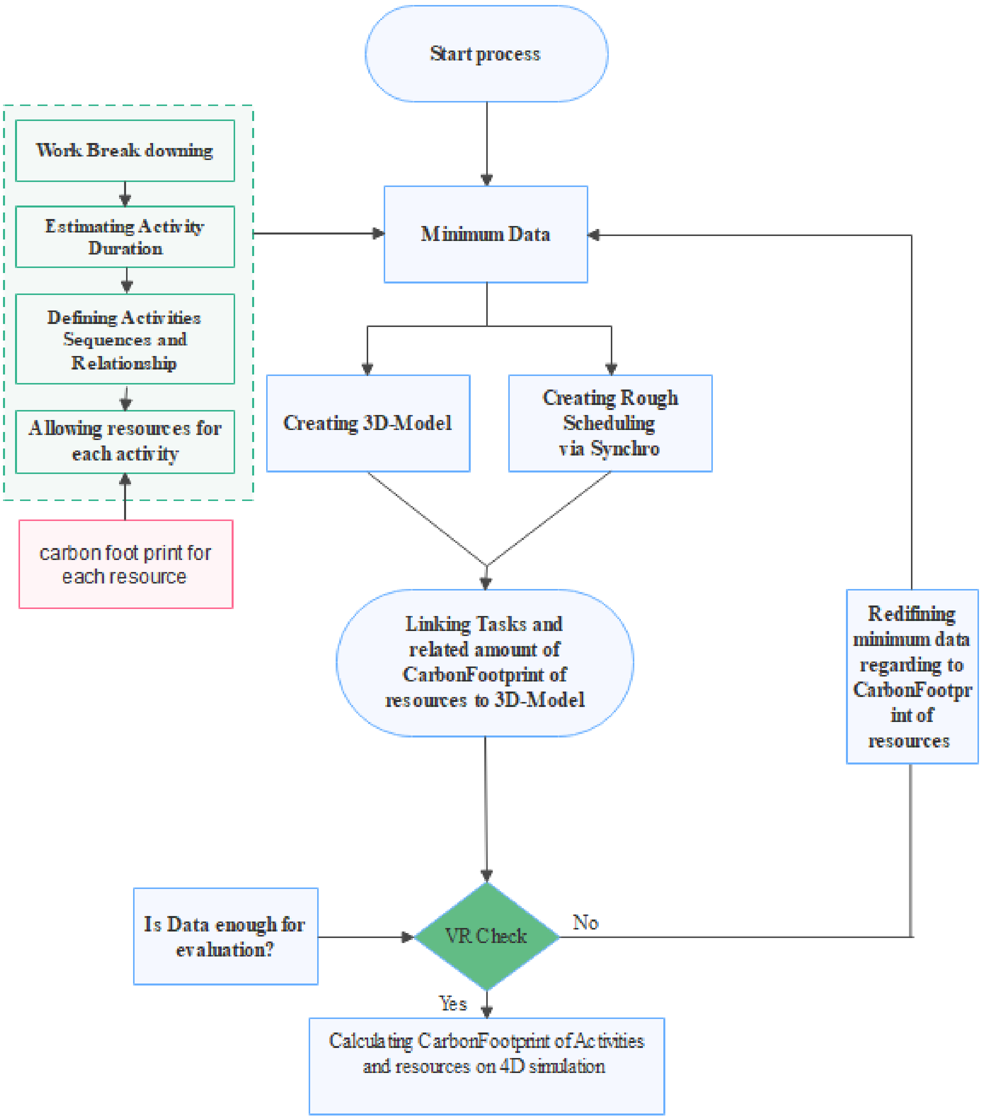


Figure 1-1: Methodology Flowchart

1.4.6 Software

Several software tools are divided into the following categories:

3D animation software, 4D BIM software, and game engine software are all examples of software that may be used to create 3D animations. Data was exchanged between software using the Industry Foundation Classes (IFC) data structure. To define the schedule, some BIM scheduling software is used.

Object-based 4D solutions include Autodesk Navisworks, ProjectWise Navigator, Visual Simulation, Synchro Professional, BEXEL, and Tekla Structures. Gantt charts, critical path approaches, last planners, and linear scheduling are some of the ways for implementing planning.

For this study, SynchroPro Bentley software package was selected to be the main research platform and the planning was created inside the software. Virtual Reality equipment (Oculus VR device) and LumenRT software can be used for visual monitoring construction procedures and data using. For importing models from Synchro to LumenRT software, Synchro control was used and an iModel Hub was created.

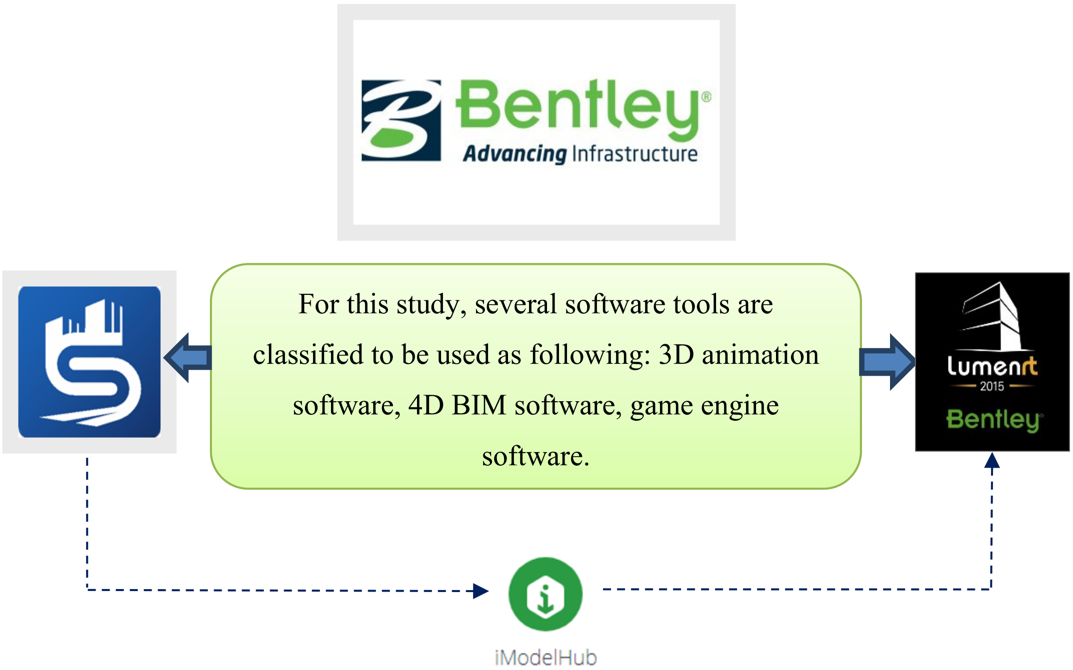


Figure 1-2: Introducing Used Software

Synchro Professional

SYNCHRO is integrated software that offers 4D planning and is able to optimize the plan of complex civil and construction projects. It also generates workspaces, animates equipment path planning, detects conflicts, and generates collision reports. This software can be highly beneficial for digital construction management because it is able to improve data to optimize decision-making by helping to optimize complex construction projects.

LumenRT

LumenRT is a piece of software that allows you to turn architectural plans into real-time surroundings. Through One-click processing, Architects, Designers, and Engineers may author their plans into lifelike immersive media directly from their CAD systems. Other features of the software include the ability to create high-quality real-time visualizations and the addition of life and nature.

1.4.7 Limitation of the study

Since there is not any information about companies that provided the materials, only the carbon emission of used concrete in the case study is calculated.

1.5 Thesis Structure

The thesis includes 4 chapters. The remaining chapters are as follows. Chapter 3 reviews through relevant literature and explains more about infrastructural planning process and 4D modeling.

Afterwards, in chapter 3 the discussion, the findings and the reflection are presented respectively. The thesis finishes with the conclusion and recommendation in chapter 4.

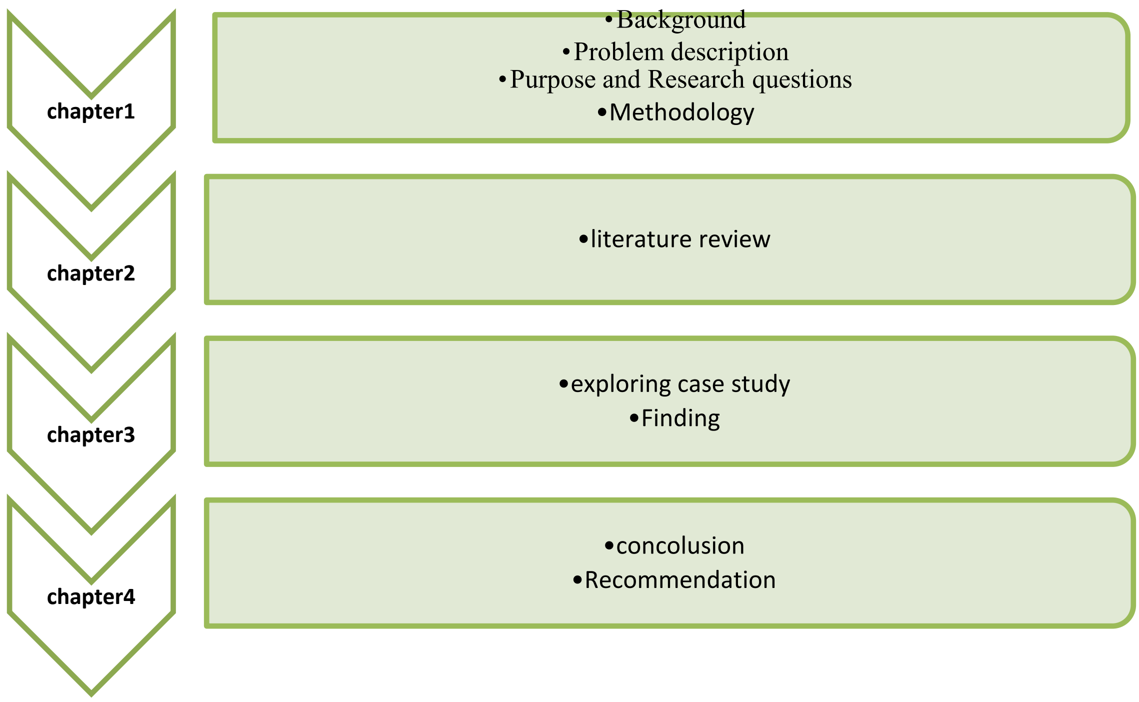


Figure 1-3: Thesis Structure

2 LITERATURE REVIEW

2.1 Introduction

In recent years, the potential of 4D BIM for constrruction industry has been proved and various studies have been done to show it. However, there is still some areas that would help to improve the scheduling process such as minimum needed data which has not been explored. This chapter includes a brief definition of keywords and comprehensive review the previous researh and frameworks in the areas of Building information modeling(BIM), 4D BIM applications, Virtual reality, Carbon emission, and the implementation of BIM in infrastructure to understand the foundation theories and technologist. this chapter is conducted to address research problems and analyse the available studies to find the gaps for this study.

2.2 Definition and Mechanisms

2.2.1 Building Information Modelling (BIM)

Professor Chuck Eastman proposed the concept of BIM for the first time, describing it as a "Building Description System (BDS) with representation based on objects storing information." (Eastmae et al., 1974). Building Information Modeling (BIM) has been defined in a variety of ways by various organizations throughout the years. For example, the NBS National BIM Library defines BIM as (NBS National BIM Library):

" BIM or Building Information Modelling is a process for creating and managing information on a construction project across the project life-cycle"

British Standard Institution (PAS1192-5:2015) also defined BIM as:

" Discrete set of electronic object-oriented information used for design, construction and operation of a built asset."

The term BIM refers to a process that allows engineers to have quick access to information, collaborate with other sectors, and visualize the virtual project in great detail. Because visualization tools provide a clearer perspective of the model, this technology has had a significant impact on the industry. BIM may help the construction sector in a variety of ways, including design, construction, operation, and maintenance. BIM can be used at many stages of a project. It may be utilized for 4D construction planning, quantity takeoff, logistics planning, and fabrication during the construction phase (Cao et al, 2014).

2.2.2 4D Modeling

For improving the construction process, increasing communication among project parties, and saving time and cost, 4D scheduling was invented. 4D scheduling is a process that involves linking time constraints to the 3D model.

The old method of scheduling was to create a Gantt Chart that simply depicted activity sequences. It's difficult to assess the constructability of scheduling using this time-consuming method. Egan Join was the first to describe the concept of a 4D Model, which links scheduling to a 3D model to simulate the construction process (Join, 1998). Scheduling was a labor-intensive manual task at the time, and it was often difficult for project stakeholders to comprehend all the data. 4D technology has evolved and increased fast in recent years to address these issues in the planning process. In fact, the model is built to connect different components of the project to the relevant work by combining 3D BIM with timetable. 4D scheduling has boost the quality and the accuracy of the construction. Koo and Fischer observed that adding time to a 3D model can help with construction management (Koo and Fischer, 2000). Due to the increased accuracy of the construction sequence and the avoidance of unanticipated conflicts throughout the construction process, recent studies look at the benefits of 4D modeling. It was demonstrated that 4D simulation may be valuable and practical in the education feild (Kang et al., 2004), (Sampaio and colleagues, 2010), (Wang et al., 2007). Safety precautions on building sites also can be analyzed using 4D simulation (Hammad et al., 2012). As well as the benefits, limitation also have been represented in researchs. Research has shown when 3D BIM models lack sufficient detail to appropriately sequence the work in a 4D model, 4D BIM is less efficient (Jacobi, 2011; Harris and Alves, 2013; Tulk et al., 2008). According to current research and practices, one of the biggest issues that arise in the construction industry's planning and execution are caused by facing too much data.

2.2.3 Machanisms- 4D BIM technologies

4D scheduling is supported by a wide range of software programs. 4D can be applied via a suit application or a stand-alone third-party. Within one application family, the Suit program may build 3D and 4D models. Data interoperability is not an issue while using this single application family. The 3D model and timetable are actually brought together when a 4D model is developed. Model designers must have a 3D model layering system that supports 4D CAD activities since 3D modeling is not built for 4D modeling (Aouad, et al., 2012). The exchange of 3D objects to the 4D model is more appropriate and transparent because BIM models break down components into little pieces. For construction planning, it is required to name projects, assign them a timeframe, and establish a relationship between them. Because all activities cannot be displayed in 4D scheduling, they must be categorized into separate groups. If good scheduling and 3D models are in place, 4D planning will be a simple and straightforward process. Recently, advanced software has been developed to allow an automated connection between 3D modeling and 4D software for this purpose. Project Wise Scheduling is now available in Bentley Navigator by importing some scheduling software such as Excel, Microsoft Project, and Primavera. Another good option for 4D scheduling is Autodesk Naviswork. This software, on the other hand, can only adjust the time between 4D state changes and not the temporal steps. TimeLiner, on the other hand, may import the timetable from a variety of sources. Another piece of software that can help with project synchronization and communication is Innovaya Visual Simulation. Since the capability of 4D planning has been demonstrated, a number of suites and stand-alone third-party 4D applications have been on the market. Table 2-1 provides an overview of these programs.

Tool	Description	Linkage	Capabilities	
			Temporal	Graphical
Synchro/Bentely	Professional 4D tool	Being able to create Gantt Chart inside the software and also importing Schedule information various scheduling application	Have several steps during a simulation . But changing the temporal step is impossible	Being able to group objects or subdivided the geometrical objects
Naviswork/ Autodesk	Being able to support different BIM format	Being able to import schedules from the variety of resources.	Being able to change time between 4D state changes. . But changing the temporal step is impossible	Being able to group objects but it does not have the ability of subdivision of the geometric objects
Visual Simulation/ Innovaya	Linking planning activities with BIM objects to create 4DBIM.	Links 3D model and data with Primavera and Microsoft Project	Being able to change time between 4D state changes. But changing the	Being able to group objects but it does not have the ability of subdivision of the geometric objects

			temporal step is impossible	
Construction Planner/Bentely	Analysing scheduling wisely	Links 3D model and data with Primavera , Microsoft Project and Excel	Being able to change time between 4D state changes. But changing the temporal step is impossible	Being able to group objects but it does not have the ability of subdivision of the geometric objects
Powerproject BIM/ Elecosoft	Combining 3D model and 4D planning and linking project plan and model in one application.	Importing the IFC files to create milestones and baselines	Being able to change time between 4D state changes. But changing the temporal step is impossible	Being able to group objects or subdivided the geometrical objects
Schedule Planner and 4D player/ Vico	Simulating the construction process including 4D and 5D	Using the link of Balanced planning to link to 3D geometric model	Being able to change time between 4D state changes. But changing the temporal step is impossible	Being able to group objects or subdivided the geometrical objects
iTWO 4./ rib software	Simulating the construction process including 4D and 5D	Developing the schedule inside the software	Being able to change time between 4D state changes. But changing the temporal step is impossible	N/A
usBIM.gantt/ ACCA Software	Simulating the construction process including 4D and 5D	Bing able to assign a time-line rellated property to each components	Being able to change time between 4D state changes. But changing the	Being able to group objects

			temporal step is impossible	

Table 2-1: Current 4D software applications

Overall, 4D technologies are able to visually depict project databases such as elements, activities, and project data like cost and material.

2.3 Application of 4D

The application of 4D can be highly beneficial for all stakeholders in different stages of the construction. The following are some of the benefits of 4D:

- Gain a better underestanding of the project by seeing the construction progress in real time.
- The ability to remove interventions at every stage of the process.
- Reducing rework by aiding the construction categorization process.
- Being able to manage project's finances.
- Increased productivity
- Increase the level of safety on the worksite
- Reducing waste by planning ahead of time and regulating the process.

In the following, the applicability of 4D in different sectors is investigated.

2.3.1 4D BIM advantages in infrastructure

Building Information Modeling (BIM) is a design method that has recently made its way into the infrastructure area, and the word (CIM) is widely used to refer to it. Yabuki presented the barriers to BIM adoption in civil infrastructure in 2010 and provided several solutions for implementing BIM in this domain. Aaron and his colleagues separated the infrastructure into five domains, which were then enlarged into thirteen categories (table-), and looked into the number of papers published in each domain. BIM for transportation infrastructure, particularly tunneling, has been relatively new in academics and industry, according to their analysis (Costin et al., 2018) The majority of existing research in the tunnel field, in particular, concentrated on integrating data management with tunnel structure. In this study, the IFC format was employed to store and share tunnel-relevant data (yabuki 2008, Hegemann et al., 2012, 2020, Osello et al., 2017). Matejov and his colleagues looked into BIM implementation in the Slovak Republic in 2021. They used surveys to determine how well-informed experts working in the railway infrastructure industry are about BIM. Only 29% of respondents were able to accurately answer the questions, according to the results. They also devised procedures for formalizing the railway infrastructure's information modeling (Matejov & Šestáková, 2021). In immersed tunnel construction, Wang also used BIM-VR application technology to analyze the tunnel's technical parameters (Wang et al., 2021)

Domains	Categories of civil infrastructure
Transportation infrastructure	Bridges
	Roads and highways
	Railways
	Mass transit
	Tunnels
	Aviation and airports
	Ports, docks, and harbors
	Non-motorized vehicle and pedestrain pathways
Energy infrastructure	Power generation
	Oil and Gas
	Mine
Utility infrastructure	Utility
Recreational facility infrastructure	Recreational facility
Water management infrastracture	Water and Water facilities
	Dams, Canals, locks, and levees.

Table 2-2: Infrastructure categories(Costin et al., 2018)

However, because BIM for infrastructure is new, a comprehensive literature review on tunneling, as a high-complexity project, has yet to be completed, necessitating extensive research and development.

2.3.2 4D BIM requirements

The requirements for 4D planning are as followed:

- Creating 3D model and defining and naming the elements and objects.
- Providing construction programm with defining tasks and thier duration and starting and ending date.
- Using 4D tools to link 3D elements to the task and time data.

2.3.3 4D BIM Implementation

The majority of study into the application of 4D BIM has revealed that the industry's rate of BIM adoption is quite low (Gledson, 2017). It can occur due to a lack of expertise, an inability to manage excessive amounts of data, or a lack of a set of standards. However, Cheng and Chang demonstrated that applying 4D BIM into the pre-construction stage can improve construction (Cheng and Chang, 2018).

2.3.4 Carbon emission

"A 'carbon footprint' is the total quantity of CO2 and other greenhouse gases emitted over a process or product's entire life cycle." (Wiedmann, Minx, 2007)

The phrase "Carbon Footprint" has gained popularity in recent years as more people realize that this is the primary cause of climate change. There are various sources of total CO2 emissions, with the cement industry being one of them. According to the International Energy Agency, 0.5-0.6 tons of CO2 are emitted each ton of cement. As a result, concrete is one of the primary sources of pollution, emitting significant amounts of ecologically polluted trash during its manufacturing, construction, maintenance, and demolition activities. Certain challenges, such as coordination, quantification and estimation, sustainability, and carbon footprint, should be considered during the project's pre - construction phase (Aouad et al., 2012).

2.3.5 Virtual Reality (VR)

Virtual reality is a word used to describe a group of technology gadgets that includes " computers, head-mounted displays, headphones, and motion-sensing gloves."

(Steuer, 1992). In fact, virtual reality allows consumers to take a virtual tour of a project before it begins development. In the table below, many types of virtual reality are described.

<table>
<tr><td colspan="7">Different types of VR systems (Wang and Li, 2004)</td></tr>
<tr><td colspan="3">Desktop VR</td><td colspan="4">Immersive VR Systems</td></tr>
<tr><td colspan="3"></td><td colspan="4"></td></tr>
<tr><td colspan="7">Different Categories of VR (Mujbar et al, 2004)</td></tr>
<tr><td colspan="2">Non-Immersive VR Systems</td><td colspan="3">Semi-Immersive VR Systems</td><td colspan="2">Fully immersive VR Systems</td></tr>
<tr><td colspan="7">Classification of VR Systems (Mengoni et al, 2016)</td></tr>
<tr><td>HMD</td><td>Curved Screen</td><td>Stereoscopic Projection</td><td>Auto-Stereoscopic Display</td><td>Holographic Display</td><td>Cave-Like</td><td>Dome-Shape</td></tr>
</table>

Table 2-3: Different type of VR

2.4 Integration and simulations

2.4.1 Integration of BIM and Carbon emission

Many academics have recently begun to experiment with BIM in the topic of sustainability (Jalaei et al., 2020; panteli et al., 2020; Singh and Sadhu, 2019). A large number of scholars attempted to develop a method for computing carbon emissions using coefficients (Mao et al., 2013; Teng and Pan, 2019) Mousaa and his colleagues suggested a method for assessing carbon footprint emissions data by combining it with BIM in order to identify carbon emission issues and reduce total pollution. (Moussa et al., 2016)

In 2013, researchers looked at data needs, carbon emission estimation techniques, and BIM integration mechanisms (Pandey, D, 2010). Simultaneously, Basbagill et al. The amount of carbon footprint emission was lowered by adopting BIM-enabled embodied impact (Basbagill and colleagues, 2013). Cang et al suggested a method for determining the embodied carbon emissions from buildings based on BIM. They demonstrated that their strategy was accurate and effective in reducing carbon emissions. (Cang et al., 2020) In addition, Rock et al. suggested a BIM-based calculating technique for evaluating a variety of construction solutions and their embedded environmental impact (Rock et al., 2018). On the Building information modeling platform, Ding et al. have developed a coefficient carbon emission technique for residential buildings (BIM) (Ding et al., 2020). Overall, it can be demonstrated that BIM can be a useful tool for calculating carbon emissions.

2.4.2 Integrated BIM Refurbishment process

The refurbishing process can benefit from the usage of 4D BIM to reduce errors and costs. In terms of coordination, energy simulation, and visualization, using BIM in this process can be extremely advantageous for refurbishment. These 4D BIM features depends on the level of geometric and non-geometric level of details and the management and analysis the data. In the refurbishment process 4D BIM helps to achieve social, environmental and financial benefit. In the refurbishment process, 3D scans can produce real-time results. Some devices, such as 3D Laser Scanning, can be utilized to achieve a precise visualization.

2.4.3 4D simulation and sustainability

Building Information Modeling (BIM) offers the potential to improve Building Sustainability Assessment by finding and evaluating multiple sustainable design scenarios early in the project, saving time, money, and other resources. BIM can be applied to many aspects of a building, including the mechanical system, fire prevention system, and energy design. Some energy simulations, such as daylight analysis, may be done with BIM technologies like Autodesk Revit. Najjar and others porved by applying BIM in the design stage of a residential building, the annual fuel consumption decreased dramatically by 45%. (Najjar, et al., 2019).

2.4.4 VR-Based collaboration in 4D

Virtual Reality technology was first used in building in 1996. Bouchlaghem et al. shown at the time that VR systems can improve both design and construction and boost the information accessibility (Bouchlagham, 1996) VR-based collaborative 4D simulation has been the subject of several scientific research and it has been shown integrating 4D BIM with VR can create the real world. VR technology is employed in building planning because computers allow for the generation and viewing of complex graphs (Dunston et al., 2005).

Sampaio and his Martins presented a virtual reality application for teaching the creation of complex sequences in 2014 (Martins and Sampaio, 2014). To simulate 4D scheduling, Kang and Kuncham employed the CAVE (Cave Automatic Virtual Environment) system. They demonstrated that as the project's complexity grows, virtual reality may help with scheduling (Kang and Kuncham, 2014).

Fischer connected many computers to video projectors so that he could view several angles of a 4D at the same time. (Fischer and colleagues, 2002). Matejka demonstrated that by utilizing 4DBIM with VR-based training methods, construction safety knowledge may be increased (Matejka. P. 2014). Boton presented four key complementing stages to help experts identify the main obstacles for 4D scheduling using a virtual reality environment (Boton, 2018). Although there have been many studies on the use of BIM and VR in AEC building projects, there have been few on the use of VR and BIM in infrastructure projects. To examine the visibility of signage, Motamedi et al blended virtual reality and BIM (Motamedi and colleagues, 2017) By combining the building schedule and resource consumption progress with the bridge 3D model, Zhou and Wang (Zhou and Wang, 2009) developed a 4D simulation model for bridge construction management. They created a 4D bridge simulation that aided construction management in reducing conflicts and avoiding resource waste. BIM has been proven to be the best way for increasing the quality of infrastructure throughout its life cycle, according to research.

As can be observed from the literature review, despite the fact that multiple diverse studies in various disciplines of 4D bim through VR have been conducted, a high level of 4D scheduling with minimal data has yet to be accomplished in the infrastructures field.

2.5 Standard data exchange and interoperability

Collectiong and managing data and implementing the best way for exchanging them is the key application of BIM. Due to the fact that managing data with different format is a tough job, applying a specefic format for exchanging data is vital. Actually, this format enables the data file to be directly integrated with the software. The most popular active data formats are xls,.xlsx,.csv,.txt, and.ifc.

2.5.1 Breif Overview of Digital Data

Merrian-Webster (2020) defined data as:

" Factual information (such as measurements or statistics) used as a basis for reasoning, discussion, or calculation that can be transmitted or processed"

Data represents facts but it is necessary to be processed to be suitable for interpretation and analysis.

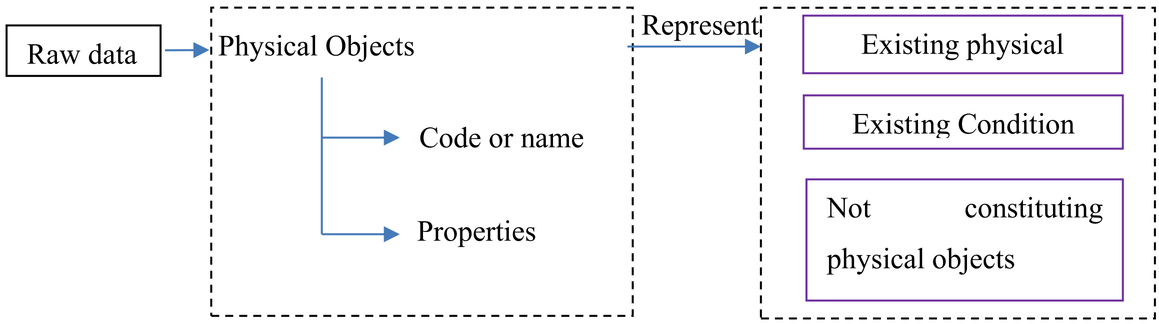


Figure 2-1: Data Definition

2.5.2 Importance of data Engineering and Construction

Data is the foundation of the engineering process and is one of the most important aspect of a project. Engineers rely on data throughout the construction process. Projects generate tremendous amounts of data as a result of the large amount of data collected before to the commencement of the project and as the project progresses. As a result, it's critical to develop techniques such as anticipating risks, increasing our project knowledge, and making proactive decisions to limit the risk of collecting too much data. It has been established that accessing accurate data, insight, and time will be impossible without sufficient understanding and a suitable method to manage the data (Shen et al., 2010). Too much data wastes time, efficiency, and human resources, and it can also lead to poor project management, resulting in excessive waste that pollutes the environment. Without managing the data there is a possibility to lost important data during the process and need to revise all the data several time. For managing data following strategies should be considere:

- Put and stored data in the safe place while stakeholders can have easy access to them
- Necessary data should be availabe in the suitable and right time. Nevertheless, there is a possibility of missing the data.
- Data should be standardised that can be used by different stakeholders in the various platform.

Unfortunately, it is seen that data and thier management is still one of the struglling concern for the enginnering and construction industry especially in the complicated projects. As it can be seen, Although data management in the design and construction phase is a tiny component of the overall project life cycle, the appropriate data can dramatically improve infrastructure design and management.

2.5.3 BIM and Digital data

BIM is known as a process of managing data. BIM is based on a three-dimensional model of the project and it consists of the elements having geometrical and non-geometrical characteristics. Geometric data include volume, size, shape, position, textures and their relationships, while non-geometric data refers to type, construction schedule, cost, material of the elements, etc. Collecting and managing data from all resources in different phases can improve the functionality of the BIM. In fact, the success of the BIM rely on finding the best way for gathering and managing dara. In recent years, BIM has become the main and the most reliable source of data. A digital flow of information from design to operation, management, and demolition must be represented inside the BIM model to achieve complete BIM capability in the Engineering and Construction (E&C) business.

The data needed for the project's construction are gathered through various means and it should bear in mind that standarddisation of the data during the process is neccesary. Data standardisation bring data into a common data format that all stakeholders with different platform can work on .There are several standards in relation to BIM data to organise and classify them and their relationships being introduced in the table1-1.

Standard	Function
UniClass2015	Organising and classifying data
IFC	Transmitting data between different software systems.
COBie (Construction Operations Building Information Exchange)	Spreadsheet data focusing on delivering information such as maintenance schedules, equipment lists and warranties.
NBS BIM Toolkit	Providing work plans to define roles for preparing data and classifying objects and their data.

Table 2-4: Existing standards in relation to BIM data

2.5.4 Data standard in Infrastructure

The term "data standard" refers to a set of technical criteria and specifications developed by an expert body (Vitasek & Zak, 2019). Due to the differences in form and components between buildings and civil infrastructure, it is important to remember that we must use separate terminology and data for civil infrastructure components and facilities. Different objects, models, data, and disciplines are used in infrastructure initiatives. Figure 2-4 and table 2-5 summarize the BIM Objects in Infrastructure.

Stages		Data
Design	Site Analysis	Location Information
	Surface Analysis	Detailed Analysis of model
	Land Survey	Topographic map
	Visualization	Model detailed
	Structural Analysis	Construction detailed
	Point clouds	Detailed capturing built environment 3D
	Signal Sighting	Testing signaling
Construction	Field Survey	Detailed information about existing condition
	Site Layout	Detailed construction plan
	Scheduling	project milestone
	Cost Control	cost-related information
	Material management	Delivery, tracking and maintenance information of material
Operation	Maintenance scheduling	Maintenance Program
	System Analysis	Tracked performance data from the infrastructure systems
	Disater Planning	Information about emergency locations
	Road/Rail Management	Workflows to build and manage infrastructure models
	Traffic Volume Simulation	Detailed operational analysis of traveling
	GIS Asset Tracking	Detailed asset information
	Water Planning	Flood mitigation information

Table 2-5:Data in infrastructure

Tunnel	Traffic	Intelligent Transport	Railway	Traffic	Intelligent Transport
		Signs and Signals			Signs and Signals
	Structure	Slab		Horizontal Track Geometry	Track Gauge
		Beam			Transition Curves
		Pile			Cant
		Anchor			Alignment Events
		Column			Reverse Curves
		Auxiliary lanes			Track Centres
	Electrical	Cable		Vertical Track Geometry	Track Grades
		Switch Box			Vertical Curves
	Drainage	Pipe			Track information and Ballast
		Subsoil Drainage		Drainage	Pipe
					Subsoil Drainage
					Open Drainage
		Open Drainage		Electrical	Cable
	Ventilation	Pipe			
					Switch Box
		Duct			

Table 2-6: BIM Objects in infrastructure

As it can be seen, because tunneling requires a large quantity of data and is quite complex, the combination of BIM and VR can help compute the necessary data to cut carbon emissions and speed up the construction process.

2.5.5 Level of Development (LOD) for Infrastructure

One of the BIM design essential is creating 3D models with high level of details. While, it has proved wrong and too much detailing also couse delayed project delivery. Despite the fact that 4D CAD is a visualization-focused technology, the amount of information required in a 4D simulation is still unknown. In fact, it is vital to point out due to the testing recent projects, 4D technology still needs to be adapted to industry needs (Boton et al., 2015). Despite the fact that 4D BIM has made significant development in recent decades, there is still a lack of thorough knowledge on what level of graphical is required for 4D planning. In fact, the amount of data which is needed to accomplish 4D scheduling processing is unknown. Boton attempted to address this issue in 2015 by creating 4D models at various stages of the design process. His research, on the other hand, was limited to pictorial details (Boton et al., 2015).

To have more dependable 4D scheduling, it is evident that temporal and graphical Levels of Detail should be properly maintained during the 4D scheduling process. Han and Golparvar-Fard, on the other hand, argue that modeling 3D without details is insufficient for 4D planning, but that it can provide a thorough picture (Han and Golparvard-Fard, 2015).

The value of the LoD is increased by the widespread use of the 4D BIM course (LOD). The LoD developed by the American Institute of Architects (AIA) is one of the most well-known schemas in this field. (AIA, 2013) and expanded by BIMForum(2017). Coordination of data is important not only for 4D planning, but also for other BIM technologies. LoD can be used as a thorough reference to improve the quality of model communication. However, no standardized LoD for infrastructure has been developed. BIMForum, in the latest version (2019) that it was published, introduced some elements of infrastructure. Due to the increasing use of BIM in the tunneling sector, the German Committee for Underground Construction (Deutscher Ausschuss für Unterirdisches Bauen- DAUB) published the LoG(Level of Geometry) definition for tunneling. (DAUB, 2019). In this committee, different levels of detail representing the model of the tunnel with different complexity and granularity are introduced in table 2-8.

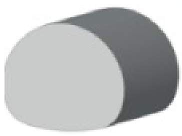
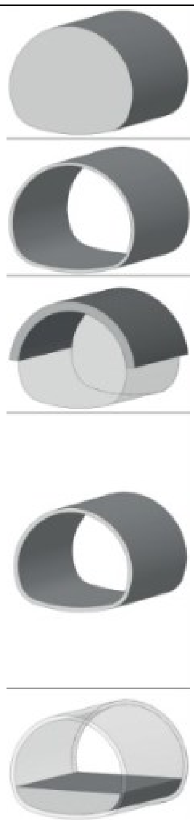
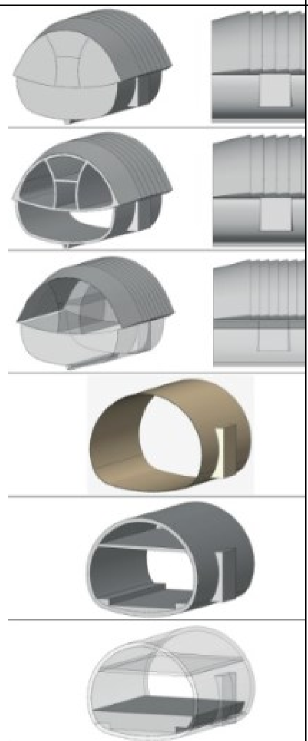
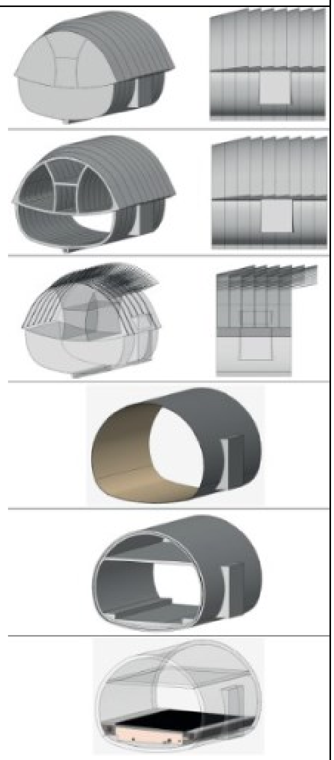
`LOG			
100	200	300	400
			
General geometric model of tunnel volume	Modeling with surface and curves, differentiated structure by boundary surface. Outer shell and the inner are separated	Representing with exact dimensions, materials and position.	Detailed and accurate representation required for the execution phase

Table 2-7: Showing the same tunnel in for different LOD

2.5.6 IFC Schema for Infrastructure

Autodesk formed an industry association in 1994 to advise the company on the development of a program to support incorporated application development. BuildingSmart created the IFC allows you to compare as-built features from model photos with as-planned models to determine the proportion of construction jobs that have been completed. The primary motivation for creating IFC was to improve data sharing capabilities (Eastman, 1999). The International Alliance for Interoperability (IAI) published the Industry Foundation Classes standard (IFC) and launched it as a data sharing standard in the following years. (Zhiliang et al., 2011). The IFC data Schema is an object-oriented model that contains semantic information and property information of the components in addition to the shape information of structure; it represents the objects, properties and relationships using entities. (Lee, 2016). BuildingSmart, introduced a general classification named *IfcCivilElementType* to define civil engineering works. The inheritance schema of the entity is shown in Figure 2-6. Properties in this entity are defined for typical infrastructure projects such as bridges and roads.

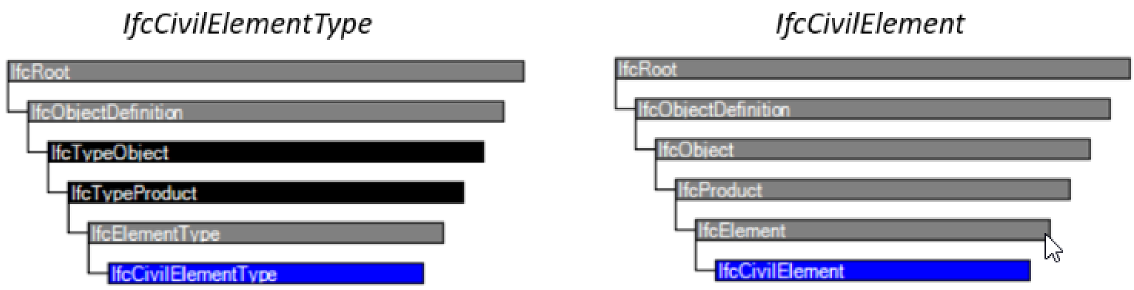


Figure 2-2: IfcCivilElememtType and IfcCivilElement inheritance schema.

However, no particular entity for tunneling has been published by BuildingSmart. The first IFC data for tunneling was proposed by Lee and Park in 2016. (Lee, Park, 2016). This IFC is heiraracy is shown in Figure 2-7.

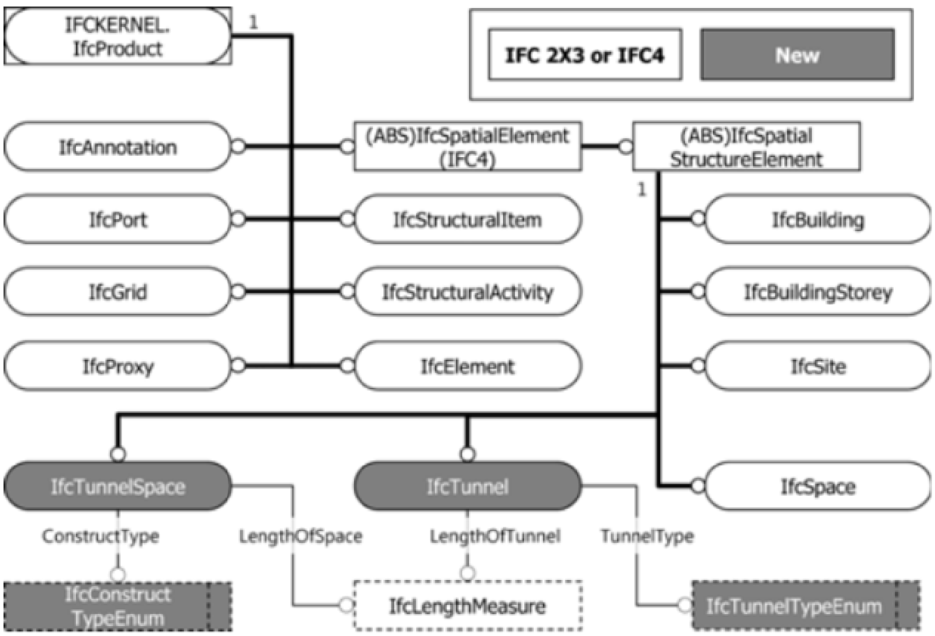


Figure 2-3: Additional IFC Spatial Elements for NATM Tunnels (Valeria et.al, 2019)

3 IMPLEMENTATION AND CASE STUDIES

3.1 General information of the Case study

The two-track, single-tube motorway tunnel, karawanken Tunnel with a length of 7.976 m is located between the stations Rosenbach (Austrian) and Jesenice (SLovenia) and therefore, in both Austrian and Slovenian territory, was chosen as a case study. This tunnel was built in the years 1901-1906 according to the principles of the old Austrian tunnel construction known as a horseshoe cross-section

The length of the whole project is approximately12.3 km and it falls into five sections: 2.5 km Slovenian side open track, Slovenian portal area, 7.975 m tunnel, Austrian portal area, 1.8 Austrian open track.

The single-tube Karawanken tunnel has two tracks and is electrified. The railway tunnel with a length of 7,975 m extends over both Austrian (4,373 m) and Slovenian (3,602 m) national territory. The north portal is located about 800 m south of the Rosenbach train station, existing km 49 + 261.90, the south portal is located in the Jesenice municipality in the village of Hrušica, existing km 633 + 662.70. The general materials used for the wall construction of the tunnel is crushed stone and stone blocks were filled with cement mortar. There are a total of 152 niches in the Karavanke tunnel, 5 "small chambers" and 2 "large chambers". Tunnel structure is introduced in the figure 3-1.

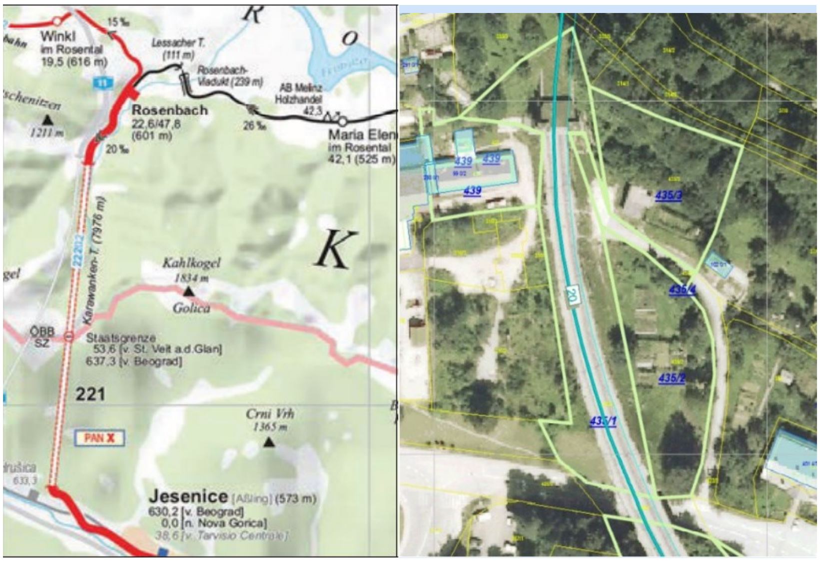


Figure 3-1: Case Study: Refurbishment of double-track Karawanken railway

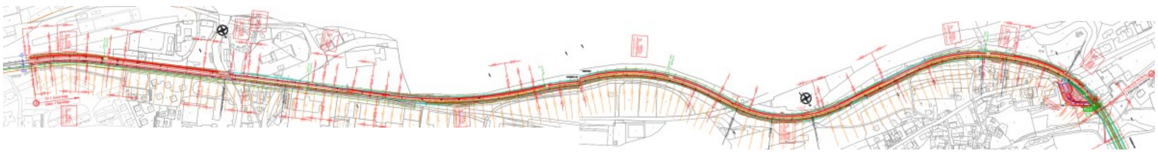


Figure 3-2: Case Study: Refurbishment of double-track Karawanken railway

Tunnel Structure	
Tunnel Length(m)	7975,27
Soffit Area (m2)	131592.00
Number Of Tubes	single-tube
Number Of Tracks	Two-Track
Type/Building Material (Exterior) Lining	stonework (natural stone)
Kilometer End	25.23572
Unrolled Length Standard Profile(m)	18.1
Unrolled Length Minimum(m)	17.82
Unrolled Length Maximum(m)	18.32
Clear Cross-Section Standard Profile(m2)	45.46
Clear Cross-section Minimum(m2)	44.48
Clear Cross-Section Maximum(m2)	46.07
(Exterior) Lining Thickness Top H (cm)	60
Min.(Exterior) Lining Thickness Top H(cm)	50
Max.(Exterior) Lining Thickness Top H(cm)	60
(Exterior) Lining Thickness Bench(cm)	70
Min.(Exterior) Lining Thickness Bench(cm)	60
Max.(Exterior) Lining Thickness Bench(cm)	75

Table 3-1: Tunnel Structure

3.2 Tunnel Refurbishment analysis

All steps that was taken to reconstruction and upgrading the tunnel is as followed:

3.2.1 Drainage system

All water flowing into the tunnel was collected in a common drainage system built into the floor vault (mixed system). The drainage channel in the floor arch was located in the middle of the cross section. The sole channel is located in the middle of the cross section and originally had an originally rectangular cross section. The diameter of this concrete pipe varies from 300 mm. There are no additional longitudinal drainage measures in the tunnel cross-section, such as lateral drainage. All the resulting water is drained from the tunnel through the central floor channel, and then flows into the reservoir on both the Austrian and Slovenian sides.

Refurbishment: The drainage system was renovated. Construction drainage in cross section concrete was pouring on slopes to the drainage of the floor vault. The existing tunnel Central drainage (mixed system) was removed and replaced by means of a new drainage pipe laid on the side (still mixed system). The renovate of the drainage system was done according to the following steps:

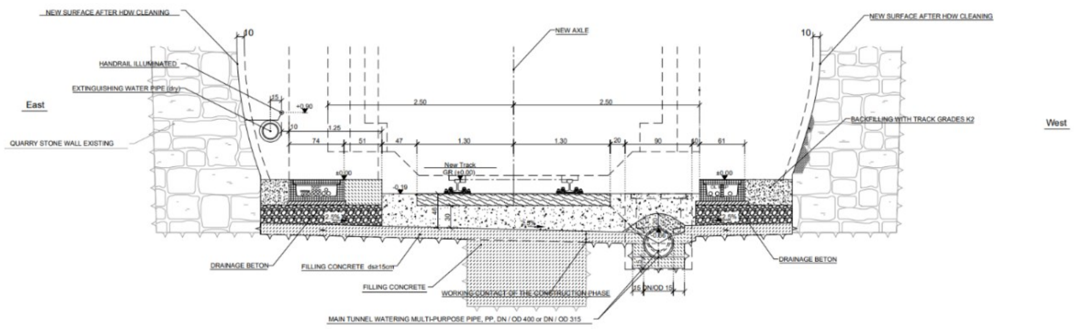
- Construction of a pit for collecting the waste water.
- Excavation for constructing reservoir

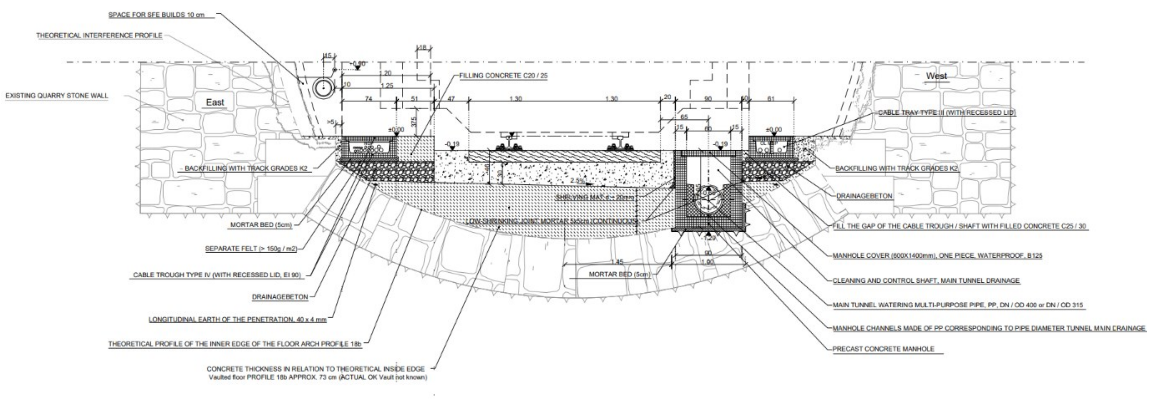
- Construction of water reservoir
- Implementation of shafts
- Construction of drainage pipes
- Backfilling of drainage pipe

3.2.2 Tunnel Track Railway

The tunnel has two railway tracks and the track spacing in (Austrian section) was approx. 3.50 - 3.52 m and in (Slovenian section) was approx. 3.45 - 3.55 m. The existing tunnel cross-section was very narrow, which means that occupational safety regulations and tunnel safety minimum requirements were not met.

Refurbishment: Two-track rearranged to single-track tunnel to have more space for safety rout. one-way peripheral route on the east side as an emergency exit route was paved. The paved peripheral route runs along cable trays of types IV and II; they have a sufficient overall width of 125 cm for this purpose. The cables are laid in cable troughs next to the tracks. Cables are type IV with recessed cover d = 6.5 cm with fire protection plate.





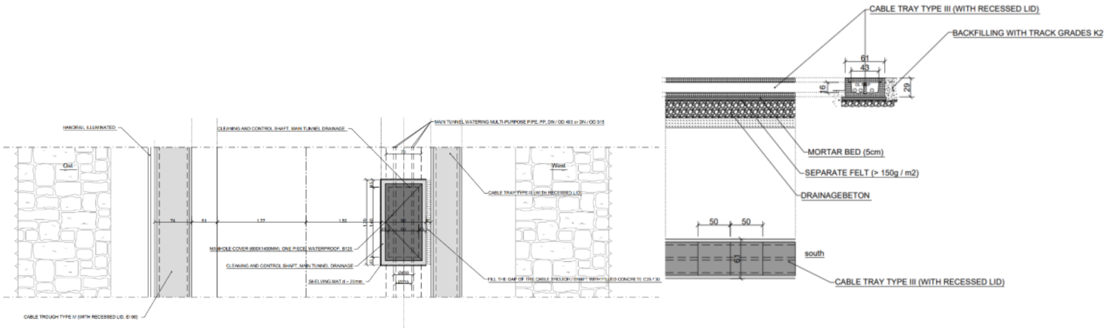


Figure 3-3: Tunnel Sections, Details, Plan

3.2.3 Tunnel Lining

The condition of the tunnel lining, made by quarry stone and ashlar masonry and brick lining in some parts, required urgent renovation measures in individual areas (masonry upgrading and / or Sealing measures).

Refurbishment: The entire surface of the arch along the entire length of the tunnel was cleaned with high-pressure water. In addition to the cleaning effect, this measure should also eliminate peeling in the walls. Finally, reinforced shotcrete with 15 cm thickness was applied to create a permanent seal on the surface and to prevent further detachment from the masonry. Tighten the further layers of shotcrete until the entire shell is applied.

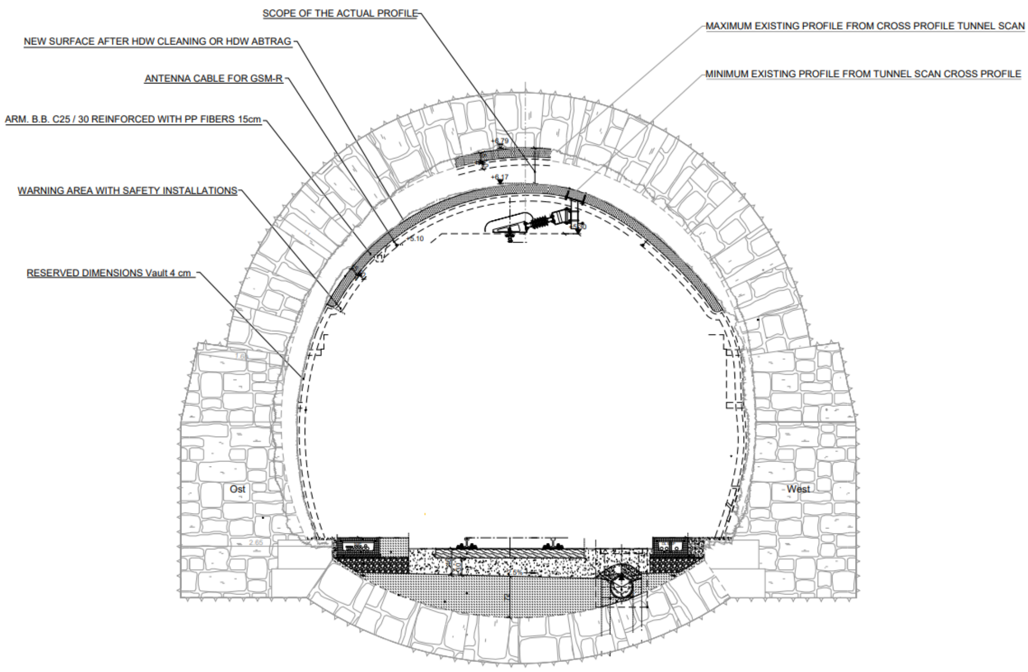


Figure 3-4: Tunnel Section- lining refurbishment

3.2.4 Tunnel niches

The tunnel has a total of 152 niches, 5 "small chambers" and 2 "large chambers", some of which are occupied by technical equipment. Most niches are located at a distance of 90-110. The niches are built of rubble and stone. The “small chambers” are approx. 920-1060m apart. The "small chambers" were lined with ashlar and quarry stone masonry. The "large chambers" are approx. 920-1060m apart from one another. The "large chambers" are located approx. 3045-3060m from the portals inside the tunnel. The lining of the "large chambers" was done with ashlar and quarry stone masonry.

Refurbishment: As an evacuation route with a handrail will be established, the original rescue function of these niches will be abandoned.

Ballast superstructure is planned in the tunnel. Form 60 E1 rails are used on impregnated oak sleepers and a ballast bed thickness of 30 cm below the sleeper.

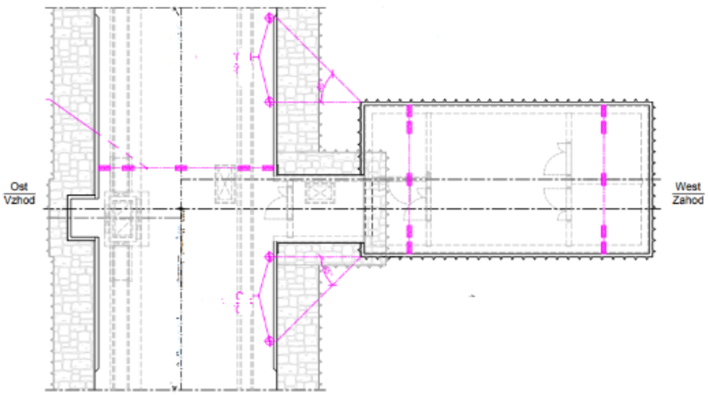


Figure 3-5: Plan of Tunnel Niches

3.2.5 TK System

Existing technical storage facilities were expanded for the needs of installing upgraded SVTK and EE equipment in the tunnel.

3.2.6 Tunnel Refurbishment analysis

Austrian Portal Building

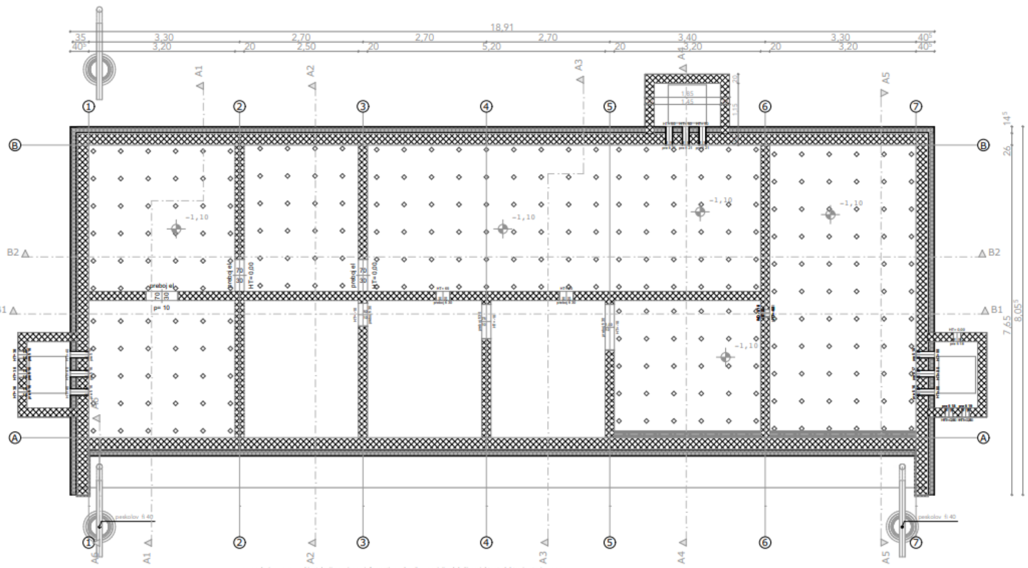
This building was built for placing electrotechnical equipment. The portal structure is a single-storey building with a flat roof, without windows, and every room can be reached from the outside through a door. It will be built using reinforced concrete. The building is consist of : MSP-EVU Room(20.48m²), MSP ÖBB Room (20.48 m²) , Transformer room (7.50 m²), Dome transformer room (7.50 m²), NSP room (16.64 m²) , Climate room (8.00 m²) and Room TK (28.8 m²).

Slovenian portal building

A control room for supplying the tunnel electricity was built. The building measuring 18.80 m x 8 m and 4.30 m high was designed with reinforced concrete walls and a ceiling slab at a height of + 3.20 m. The building is thermally insulated, the perimeter walls were covered with 15 cm of thermal insulation, and the roof with 25 cm of thermal insulation. The Facade was insulated with a 15 cm layer of stone wool. Final layer of the front facade is an aluminum expanded sheet in aluminum frames on system spacers. The walls were reinforced concrete, careful visible concrete with an anti-dust coating. The walls adjacent to the transformer compartments were lined with thermal insulation and fiber cement board coating

The roof of the building was made as a flat roof with a minimum slope. For all layers, Thermal insulation with 25 cm thickness was provided. The roofing was made of pvc foil 1.8 mm thick, e.g.

All doors of the building were made of 65 mm wide aluminum profiles. All doors except doors in rooms for transformers were implemented with an interrupted thermal bridge, with a thermal insulation factor Uw = 1.6W / m2K.



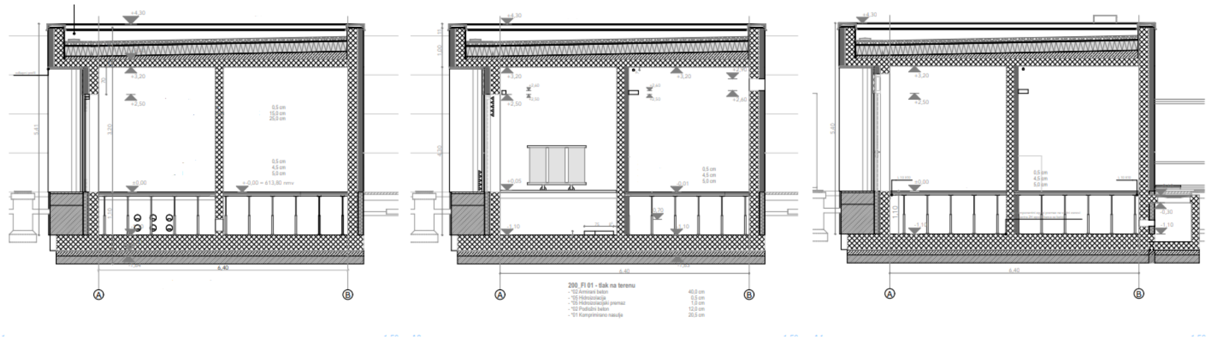


Figure 3-6: Slovenian Building Portal plan and Sections

3.3 Model data and exchange analysis

Planning of the large infrastructure projects such as tunnels needs considering different scales. The first stage involves identifying the components of the project and the activities involved in its refurbishment. It should be mentioned that the database of the tunnel structure are based on the following principles:

- Each element divided hierarchically into individual classes
- Properties are not assigned directly to classes and the they include graphical and non-graphical data
- Multiple property assigned to a single element
- Properties have their specified data type

3.3.1 Project information model break down structure

For understanding the complex models such as tunnel, the model should be subdivided into smaller significan and essential sub-models. Components of the model should be decomposed to optimize the model For this study, it is also vital to decompose the mode to be able to recognise the data much more clearly. It is obvious that decomposition of the component should be done under a standard to analyze and optimize. For achieving this, Industry Foundation Classes (IFC) were used.

Structural Elements `	Ring		Ring Refurbishment Surface(m2)
			Ring Refurbishment Measure
	Nische		Niche Refurbishment Measure
			Niche Refurbishment Surface(m2)
	Drainage	Longitudinal Drainage System Symbolic Axis	Length(m)
			Diameter(mm)
			Width(mm)
			Height(mm)
			Material
			Lid Type
			Lid FasteningType
			Lid Weight(kg)
		Transversal Drainage System Symbolic Cube	Length(m)
			Diameter(mm)
			Width(mm)
			Height(mm)
			Material
			Lid Type
			Lid FasteningType
			Lid Weight(kg)
		Drainage Pipes	Line Start
			Line End
			Line Length(m)
	Track	Attributes for all elements	Start Chainage(km)
			End Chainage(km)
			Thickness(m)
			Volume(m3)
		Ditch	Ditch Length(m)
			Ditch Width(m)
			Ditch Type
		Rail	Rail Type
			Fastening Material Type
		Track-Sleeper	Track Type
			Sleeper Type
			Sleeper Dimension(m)
		CableDuct	Cable Duct Length(m)
			Cable Duct Width(m)
			Cable Duct Type

Table 3-2: model break down structure

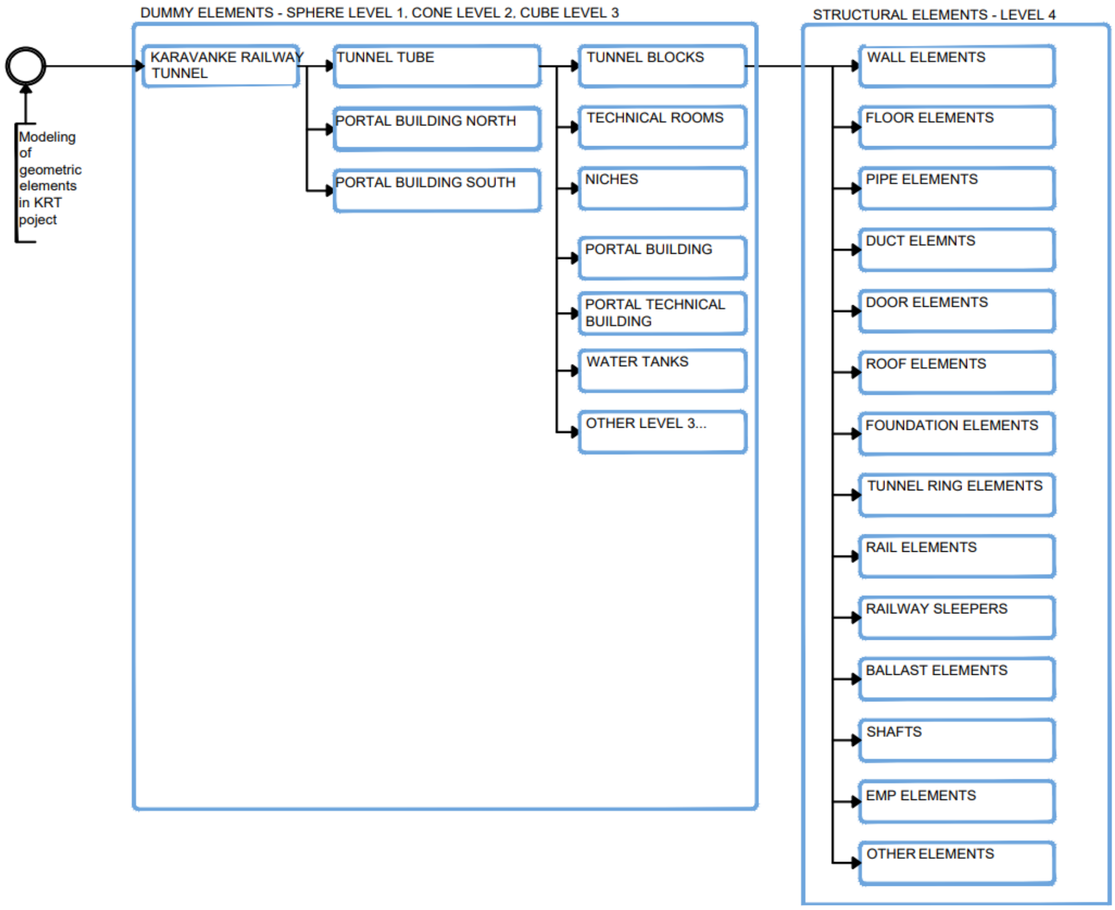


Figure 3-7: Introducing the Geometric Elements used in the Tunnel

3.3.2 Geometry and LOG (Level of Geometry)

In the infrastructure models, elements size, shape, location, quantity, orientation with detail should be represented. As it can be seen in literature review, a single graphical LOD is not enough for creating 4D planning. Actually, it is necessary that different levels of development be prepared to be visualised and coordinated. Therefore, all elements are modeled with LOD 300 in this study. While, it is proved it is important to retain the level of graphical detail for applying 4D simulation, lack of detail does not change the whole process of planning (Heesom, 2004). Consequently, although the provided LOD is not sufficient enough for tracking all the process, it can provide an overview of the process. The total shape of the elements are defined while some of their objects and details are ignored. Quality, size, shape, position and coordination of all elements are defined and recognisable.

3.3.3 Metadata and LOI (Level of Information)

Properties define the details of the model, objects and individual elements. Different characteristics of the model such as width, height, diameter etc are provided in properties. About scheduling and increasing the visualization, the level of detail given in 4D modeling is vital. Since showing all activities in 4D modeling is impossible, all activities should be classified into various categories.

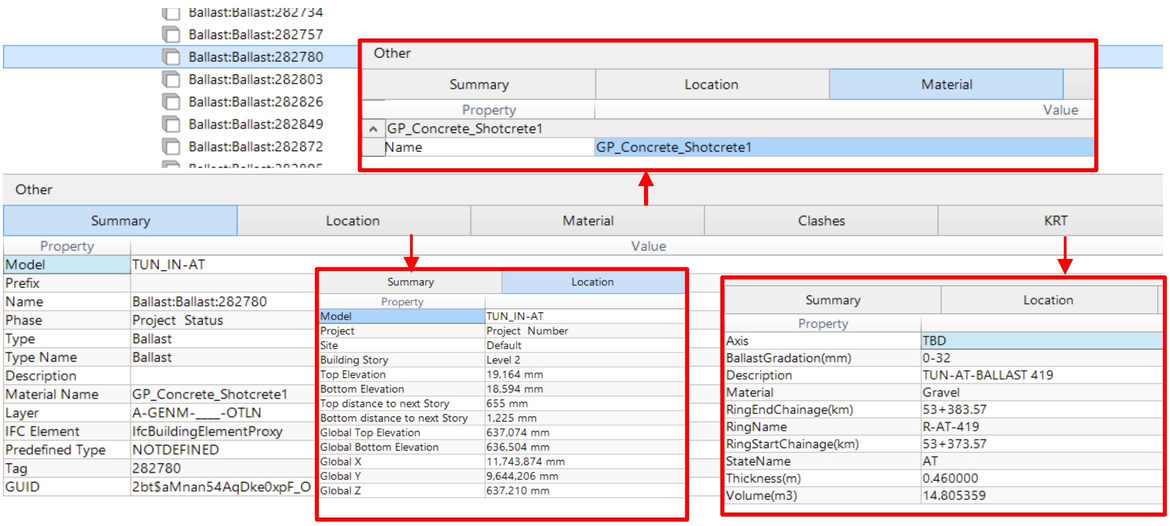


Figure 3-8: Data in Properties

3.3.4 Information exchange issues

Data exchanging between different stakeholders is one of the most crucial importance that should be considered. Since, in this study, data come from several disciplines in different formats and tools, data and information exchange is complex. A rigorous data checklist assists modelers in determining the availability of deliverables to create the 4D model once the exact information is gathered. A rigorous data checklist assists modelers in determining the availability of deliverables to create the 4D model once the exact information is gathered.

3.3.5 Interoperability

The 3D model and 4D model are created within one application family to prevent issues of data interoperability. Using the open data formats to share multi scale models while keeping the consistency of the model is vital. In these projects, use IFC format to transfer models from one application system to another. This format is used to represent every aspect of the design and construction.

3.4 4D BIM Implementation

For doing 4D scheduling, naming activities and defining their relationship and duration is necessary. All activities should be divided into different categories due to the fact that showing all activities in 4D scheduling is impossible. Infact, 3D models have to be structured to the objects and components to be able to match to schedule. For producing planning, projects activities and their duration and relationships should be namedand specified. It is also should be noticed that the 3D model and the scheduling establish in a way that their linking and connecting be a direct process

3.4.1 Input: available data-sets

All elements were divided according to their location. Tunnel was divided into two Austrian and Slovenian parts and all elements were divided into several objects. Subdivision of elements and aggregation of them are necessary to create the geometry of 4D planning. For all objects, providing ID, type and name of the objects are necessary. With this clarification, it is more understandable which data are necessary to consider.

Tunnel lining

Tunnel lining refurbishment consists of two steps, in the first step the damaged parts of the linings are demolished via high pressure water. In the following step the lining is reinforced via shotcrete. For doing these, 16 and 31 objects were defined and modelled respectively.

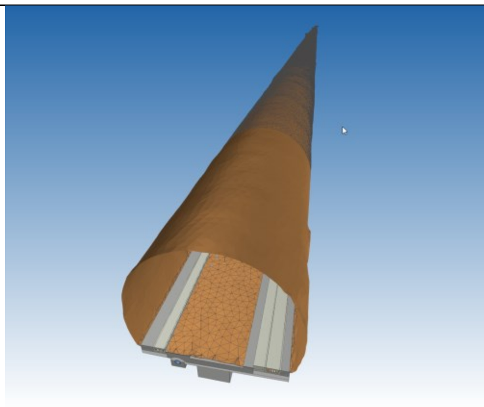
LOI	**Geometry**	
Name	Swept Area Solid	
Block start chainage- km		
Block end chainage- km		
Top elevation		
Bottom elevation		
Top distance to the next story		
Bottom distance to the next story		
Global X		
Global Y		
Global Z		
Volume		
Thickness		
Material		

Table 3-3: LoI and LOG of the tunnel lining

Tunnel sleepers

Tunnel sleeper is model was devided to 9 (different objects) part according to their locations (Start chainage-km and end chainage-km).

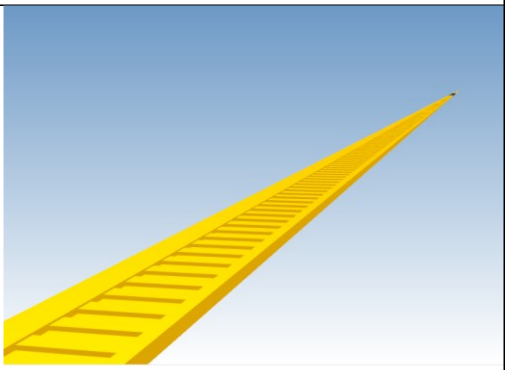
LOI	**Geometry**	
Object ID	Swept Area Solid	
Block start chainage- km		
Block end chainage- km		
Top elevation		
Bottom elevation		
Top distance to the next story		
Bottom distance to the next story		
Volume		
Material		

Table 3-4: LoI and LOG of the tunnel Bal

Tunnel ballast beneath the rail

Ballast are modeled to support concrete sleepers. This element are divided into 410 objects.

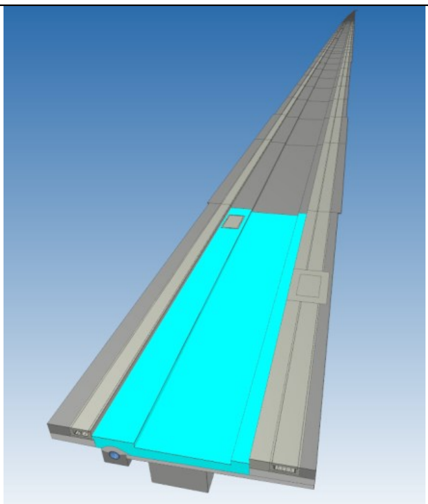
LOI	**Geometry**	
Object ID	Swept Area Solid	
Block start chainage- km		
Block end chainage- km		
Top elevation		
Bottom elevation		
Top distance to the next story		
Bottom distance to the next story		
Global X		
Global Y		
Global Z		
Volume		
Thickness		
Material		

Table 3-5: LoI and LOG of the tunnel ballast beneath the rail

Tunnel base concrete

These elements divided into the smaller parts. 831 objects were defined.

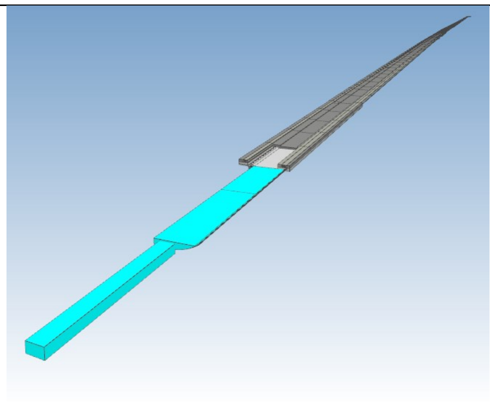
LOI	**Geometry**	
Name	Swept Area Solid	
Block start chainage- km		
Block end chainage- km		
Top elevation		
Bottom elevation		
Top distance to the next story		
Bottom distance to the next story		
Global X		
Global Y		
Global Z		
Volume		
Material		

Table 3-6: LoI and LOG of the concrete base of the tunnel

Concrete layer of the bottom of the sleeper

For doing this part, 423 objects were defined.

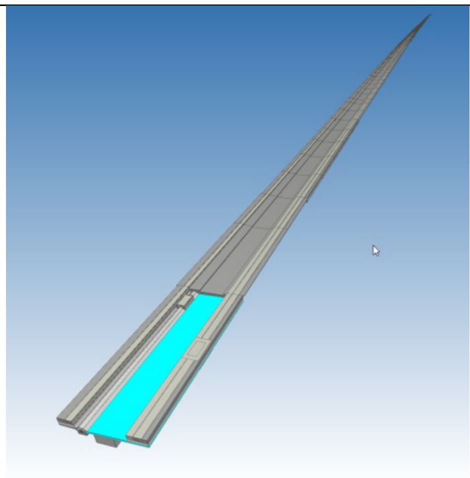
LOI	**Geometry**	
Name	Swept Area Solid	
Block start chainage- km		
Block end chainage- km		
Top elevation		
Bottom elevation		
Top distance to the next story		
Bottom distance to the next story		
Global X		
Global Y		
Global Z		
Volume		
Thickness		
Material		

Table 3-7: LoI and LOG of the concrete layer of the bottom of the sleeper

Rail

Rail element is divided into 4 object.

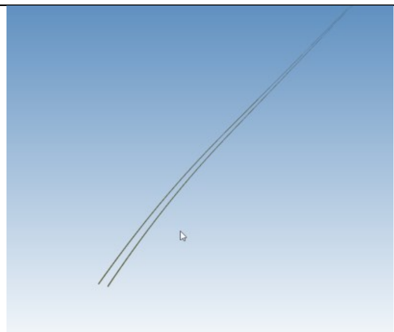
LOI	**Geometry**	
Object ID	Swept Area Solid	
Block start chainage- km		
Block end chainage- km		
Top elevation		
Bottom elevation		
Top distance to the next story		
Bottom distance to the next story		
Axis		
Material		

Table 3-8: LoI and LOG of the Rail

Tunnel TK

The overhead line elements are divided into 284 objects. It is also mentioned that the line holders are considered a part of overhead line installation tasks.

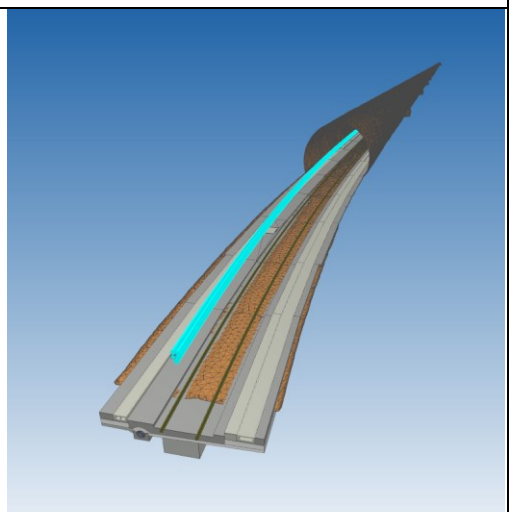
LOI	**Geometry**	
Name	Swept Area Solid	
Kilometer end		
Kilometer start		
Length		
Top elevation		
Bottom elevation		
Top distance to the next story		
Bottom distance to the next story		
Global Top Elevation		
Global Bottom Elevation		
Axis		
Material		

Table 3-9: LoI and LOG of the tunnel TK

Drainage system

Different elements of the drainage system are introduced in the 3-11 table. All of the elements are divided into various objects. It should also mention that shafts are considered as a part of installation of base concrete of the drainage system.

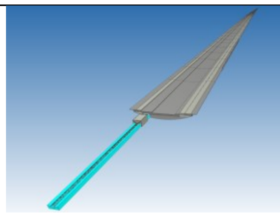
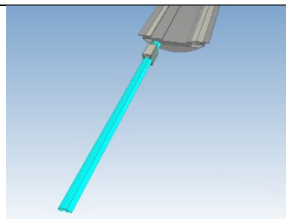
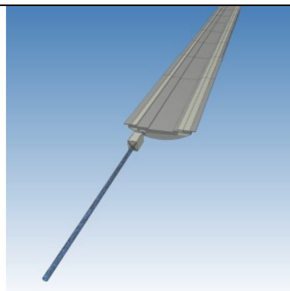
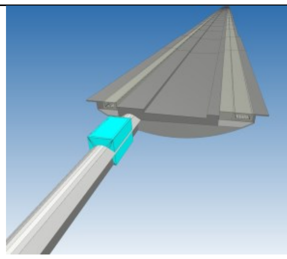
LOI	**Geometry**		
Name	Swept Area Solid	Base concrete of drainage pipe (863 objects)	
Block start chainage- km			
Block end chainage- km			
Top elevation		Top concrete of drainage pipe (858 objects)	
Bottom elevation			
Top distance to the next story			
Bottom distance to the next story		Drainage pipe (852 objects)	
Global X			
Global Y			
Global Z			
Volume			
Material		Shaft	
Shaft depth			
Shaft location	Model in place		
Shaft depth			

Table 3-10: LoI and LOG of the tunnel drainage system

Niches

The tunnel has a total of 152 niches, 5 "small chambers" and 2 "large chambers". General data related to the niches should be considered for 4D planning.

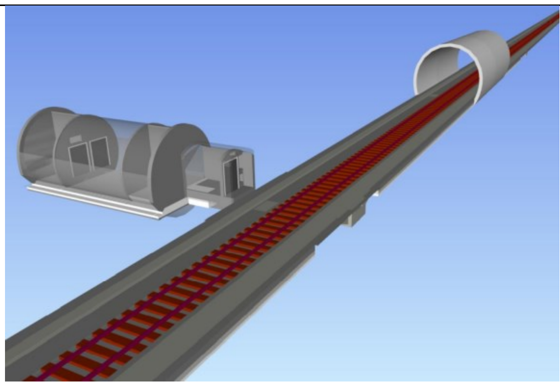
LOI	Elements	Picture
Name	Wall	
Type	Duct	
Length	Pipe	
Width	Floor	
Material	Slab	
Location	Inner lining	
Height	Door	
Volume		
Thickness		

Table 3-11: LoI and LOG of the tunnel niches

East side of the railway

The construction of the floor of the tunnel is divided into two sides, west and east. During the construction, after rehabilitation of the base of the floor, first the west side of the railway is reconstructed and the east part is refurbished in the next step. It should be mentioned that all the elements' installation must be coordinated. It is crucial for decreasing issues during the creation of 4D planning.

All the elements and objects are introduced in the table 3-13 and 3-14.

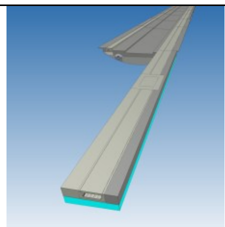
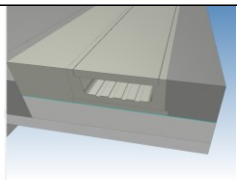
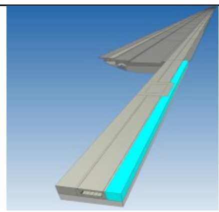
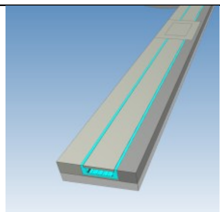
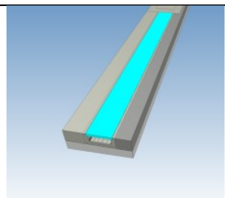
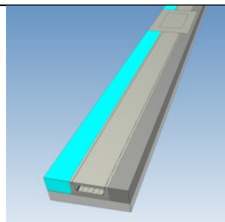
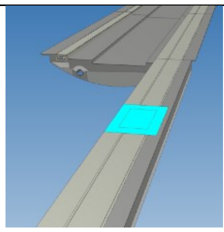
LOI	**Geometry**		
Name Block start chainage- km Block end chainage- km Top elevation	Swept Area Solid	Base concrete of drainage side (805 objects)	
Bottom elevation Top distance to the next story Bottom distance to the next story		Ditch membrane(810 objects)	
Global X Global Y Global Z Volume		Filling ditch side with ballast and shotcrete (807 objects)	
Material Ditch length Ditch width		Ditch(807 objects)	
Top ditch length Top ditch width Shaft depth Shaft location		Top of the ditch(807 objects)	
		Concrete side(807 objects)	
	Model in place	Shaft	

Table 3-12: LoI and LOG of the east side of railway

West side of the railway

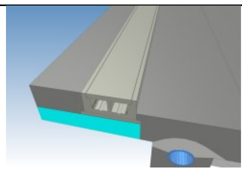
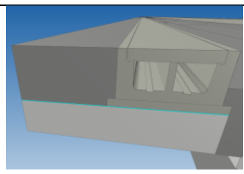
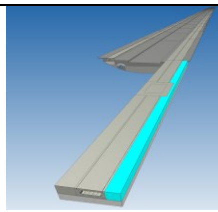
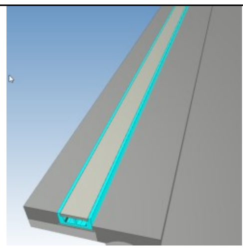
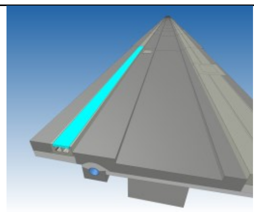
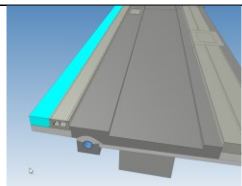
LOI	**Geometry**		
Name	Swept Area Solid	Base concrete of drainage side (808 objects)	
Block start chainage- km			
Block end chainage- km			
Top elevation			
Bottom elevation		Ditch membrane (808 objects)	
Top distance to the next story			
Bottom distance to the next story			
Global X		Filling ditch side with ballast and shotcrete	
Global Y			
Global Z			
Volume		Ditch	
Material			
Ditch length			
Ditch width			
Top ditch length		Top of the ditch	
Top ditch width			
Shaft depth			
Shaft location		Concrete side	

Table 3-13: LoI and LOG of the west side of the railway

Tasks and Time

Each step of refurbishment needs a specific time based on the planned tasks. Due to the fact that the amount of data should be minimized, overall scheduling is considered instead of micro-scheduling. It should also mention that, as task duration is hard to plan, anticipated tasks are generally assumed. For increasing efficiency, all next tasks start when previous tasks are completed. In the table 3-15 tasks and start, duration and finish time are specified.

Task name	Duration	Planned start	Planned end
Demolishing of the existing vault with high water pressure	13 Days	1/10/2020	13/10/2020
remediation works in lining	15 Days	24/10/2020	7/11/2020
Renewing tunnel niches	21 Days	7/11/2020	27/11/2020
Dismantling of existing tracks	12 Days	28/11/2020	8/12/2020
Removel of the track ballast of east part of the floor	8 Days	8/12/2020	15/12/2020
Installation of the base of concrete in the east part of the floor	7 Days	16/12/2020	22/12/2021
Concrete layer of the bottom of the sleeper in the east part of the floor	5 Days	23/12/2020	7/01/2021
Removel of the track ballast of west part of the floor	5 Days	23/12/2020	7/01/2021
Dismantling of the existing base to the drainage ditch	8 Days	8/01/2021	15/01/2021
Installation of the base of concrete in the west part of the floor	8 Days	16/01/2021	23/01/2021
Installation of the base concrete of the drainage	3 Days	24/01/2021	26/01/2021
Installation of drainage pipe	7 Days	27/01/2021	02/02/2021
Installation of the concrete above the drainage pipe	3 Days	03/02/2021	05/02/2021
Installation of membrane	2 Days	10/02/2021	11/02/2021
Installation of bottom of the ditch	2 Days	12/02/2021	13/02/2021
Installstion of ditch	2 Days	14/02/2021	15/02/2021
Installation of top of the ditch	2 Days	17/02/2021	18/02/2021
Installation of drainage side	2 Days	18/02/2021	19/02/2021
Installation of drainage backfill	2 Days	20/02/2021	21/02/2021
Filling slab with concrete	2 Days	11/02/2021	12/02/2021
Installing concrete side	2 Days	13/02/2021	14/02/2021
Installing membrane	2 Days	15/02/2021	16/02/2021
Installing bottom of the ditch	2 Days	17/02/2021	18/02/2021
Installing ditch	2 Days	19/02/2021	20/02/2021

Installing the top of the ditch	2 Days	21/02/2021	22/02/2021
Installing drainage backfill	2 days	23/02/2021	24/02/2021
Installing ballast beneath the track	3 Days	25/02/2021	27/02/2021
`Rail Beam installation	13 Days	27/02/2021	11/03/2021
Installation of railway tir	5 Days	28/02/21	4/03/21
Construction of portal building of Slovenian part	53 Days	5/04/2021	27/05/2021
Construction of portal building of Austrian part	74 Days	5/04/2021	17/06/2021
Installation of overhead line and TK	36 Days	11/04/2021	16/05/2021

Table 3-14: Tasks and Time data

For minimizing the imput data, the ditch part of the tunnel is modeled several times and imported into the Synchro platform and in every steps some of the information is minimized to investigate the minimum amount of required data. According to this experiment, the minimum data needed for creating 4D modeling is according to figure 3-9.

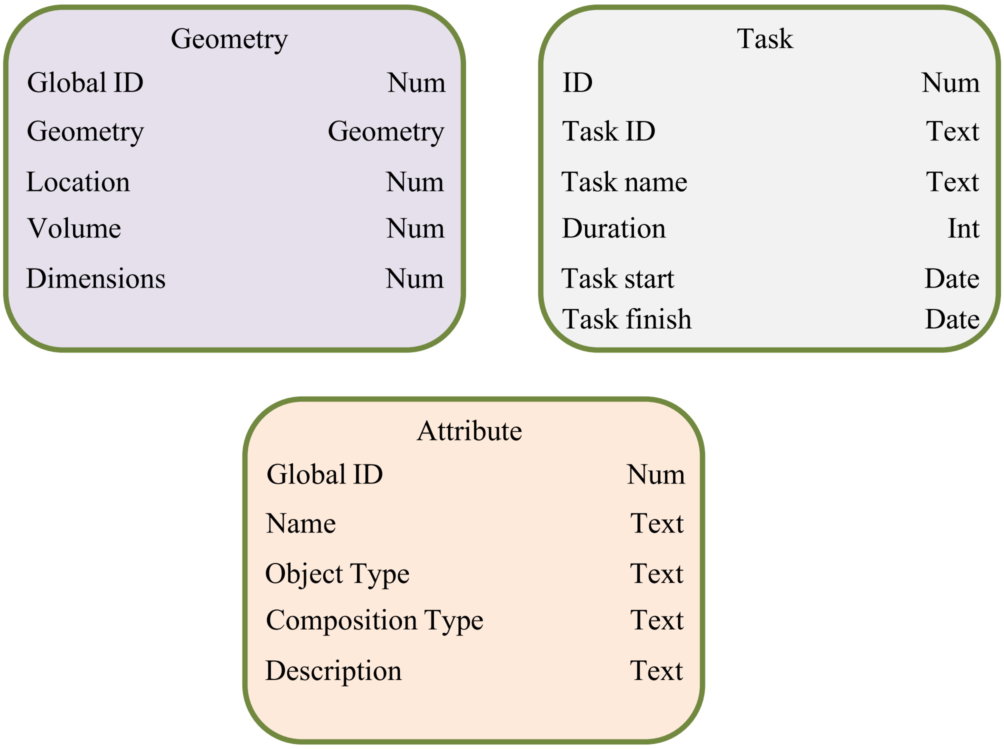


Figure 3-9: Minimum required data for starting 4D simulation

3.4.2 Process: 4D modelling

As it mentioned before, creating effective 4D planning causes successful project execution. In this study, 4D planning are created according to following steps:

1- Importing IFC file of the 3D model in to the Synchro

2- Creating Gantt Chart inside the Synchro

Tasks, their duration, start date and end date and their relationships were defined inside the software.

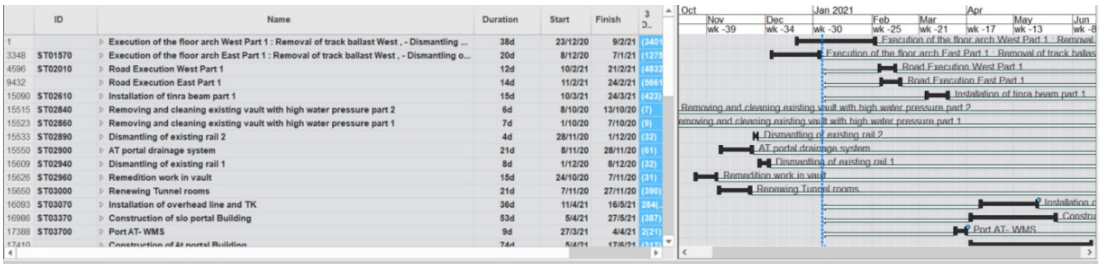


Figure 3-10: GanttChart of the case study

3- Linking tasks to the 3D objects

All the objects were selected seperatly and assigned to the related tasks.

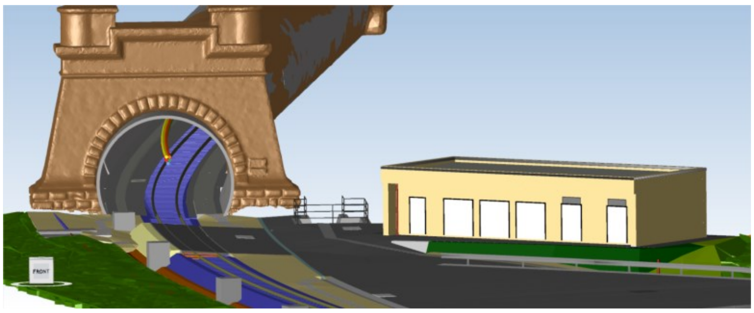


Figure 3-11: Assigning tasks to the 3D model

In the figure 3-13 all tasks and their sequencing are introduced.

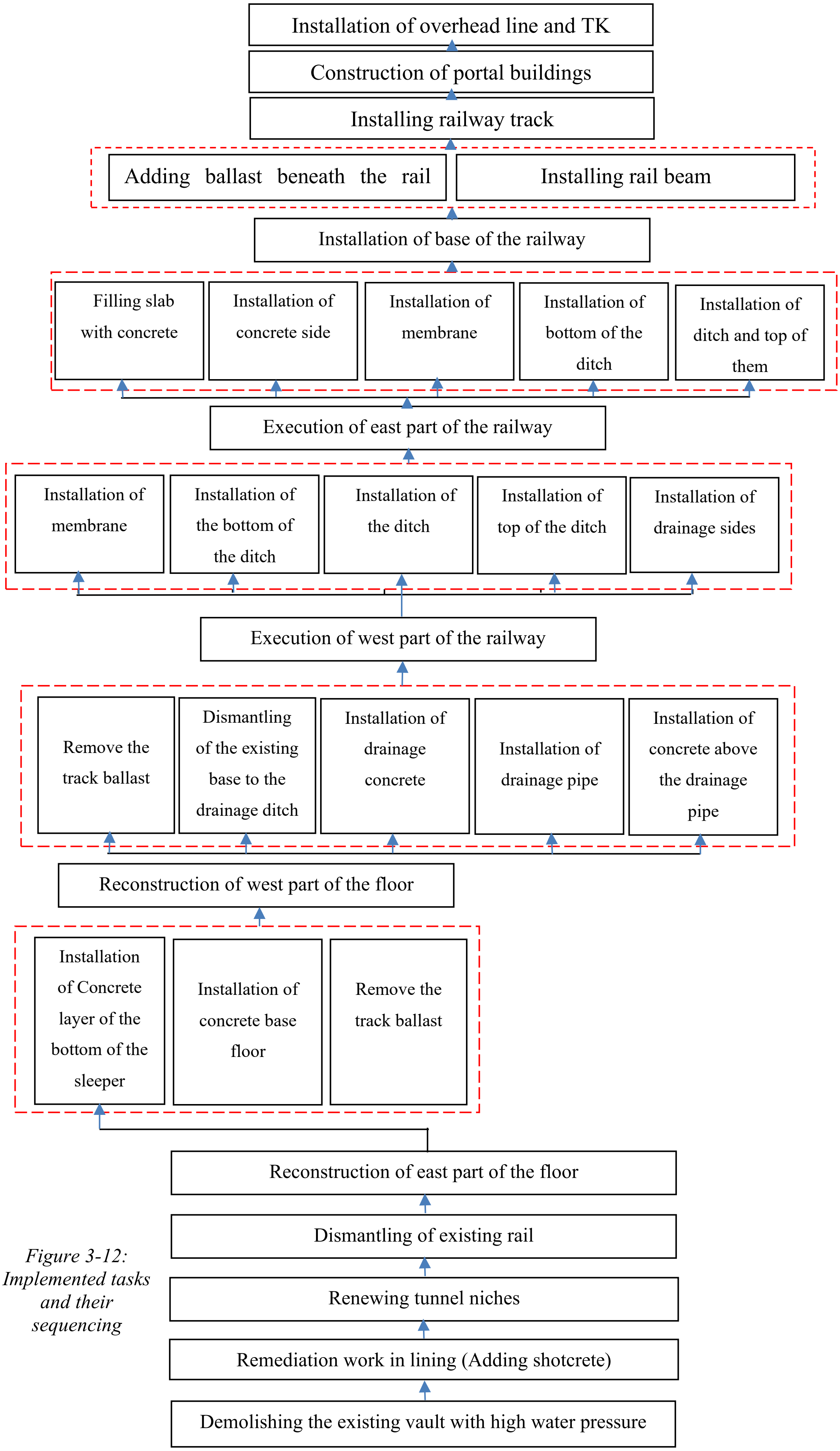


Figure 3-12: Implemented tasks and their sequencing

4- Calculating carbon footprint of the concrete elements

For doing this part, all the concrete objects are filtered and assigned different color to be able to recognised via software and the formula for calculating their carbon emission defined. According to the International Energy Agency, 0.5-0.6 tons of CO_2 are emitted each ton of cement. Therefore, the formula is defined according to this as follow:

CFP= V*1.54

V= Volume

CFP= Carbon Foot Print

Then the CFP column is created and added to the Gantt Chart to calculate the amount of carbon emission of each resource. In the figure 3-11 the tasks and their sequence are introduced.

User Field	Value	Type
[KRT]Axis	TBD	String
[KRT]BallastGradati...	0-32	String
[KRT]Description	TUN-SLO-BA...	String
[KRT]Material	Gravel	String
[KRT]RingEndChain...	633+674.00	String
[KRT]RingName	R-SLO-001	String
[KRT]RingStartChai...	633+664.00	String
[KRT]StateName	SLO	String
[KRT]Thickness(m)	0.34	Number
[KRT]Volume(m3)	2.17	Number
CFP	3.34	Number
IfcBuildingStorey	Level 1	String
IfcElementTag	282183	String
IfcGUID	0rrQd6eB16$...	String
IfcMaterial	GP_Concrete...	String
IfcPresentationLayer...	A-GENM-___...	String
IfcRelatedType	Ballast-L_BrT	String
IfcRelatedTypeClass	IfcBuildingEle...	String
IfcSite	Default	String
IfcType	IfcBuildingEle...	String

Figure 3-13: The picture of adding carbon footprint (CFP)in the user field of one object in Synchro

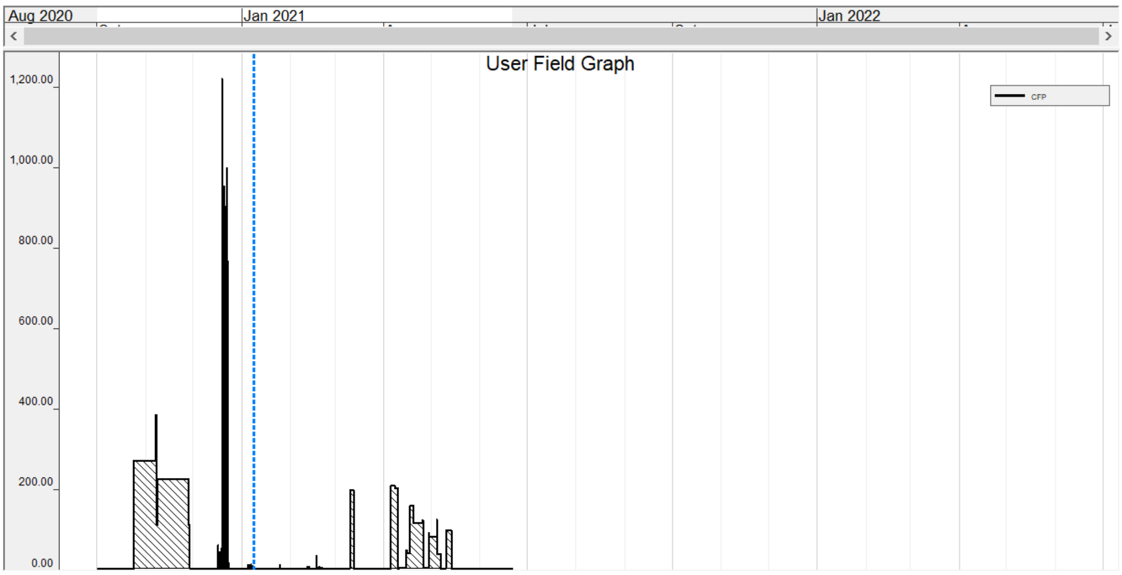


Figure 3-14 Calculating the amount of carbon footprint of each object over the time

3.4.3 Output: 4D simulation

After linking all tasks to the objects, the model is exported and imported to the LumenRT software to have a better visualization and check the data in order to minimize them. Poit cloud also are added to the LumenRT to be able to make a decision.

To gain information in the study, following issues should be considered.

- Modeled geometry should be consistent, existing any inconsistency in the 3D model creates too much useless data and Couse rework.

- All objects should have their necessary data to be able to create 4D planning and calculate their carbon footprint. (Data such as their location, ID, name, material , volume)

- 3D objects should not be modeled with a high level of development, having too much detail in a 3D model can lead to creating a huge amount of data (most of the time inaccurate and inconsistent data).

- All the tasks and their dependencies should be defined clearly to avoid creating useless data.

Modelers must assess the 3D model as the project advances and make any necessary modifications.

The creation of superior 4D prototypes is aided by frequent evaluations and revisions to a 4D model.

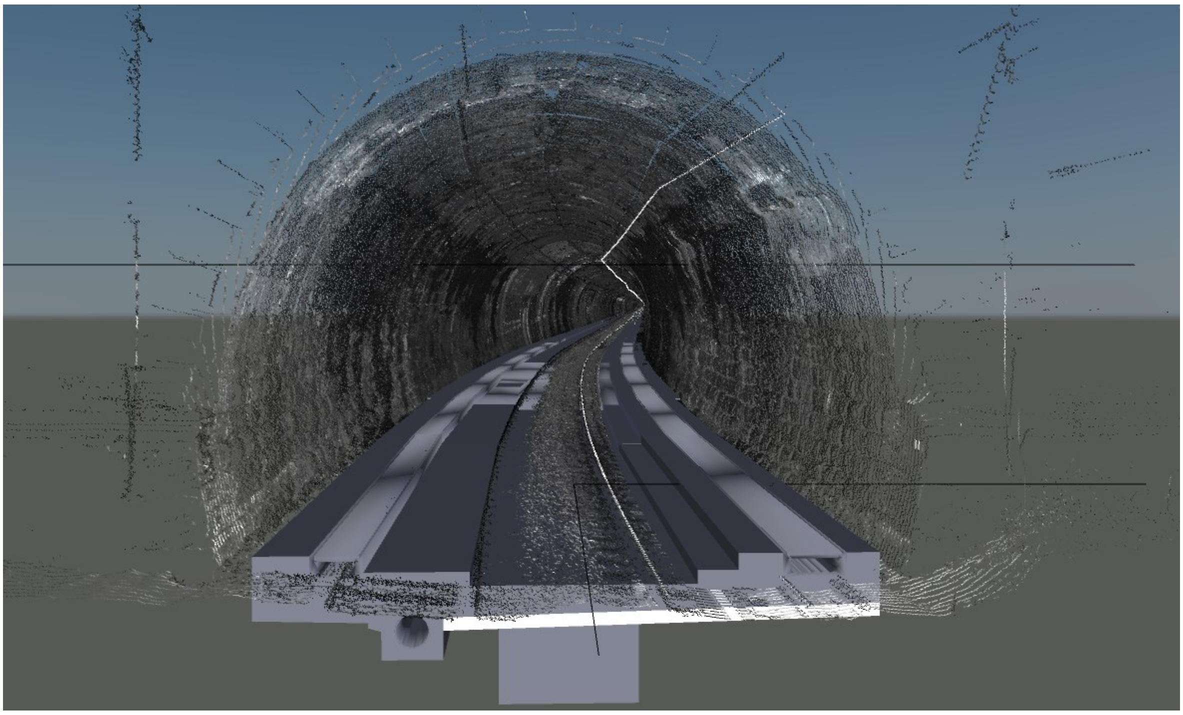


Figure 3-15: Importing and Integrating point cloud and the 3D model

According to the investigation, Firstly, as all the existing elements, becouse of the size of the project, were devided into around 800 objects, the scheduling was time consuming and not applicable in the real construction site. The number of existing objects of those elements that were devided into many parts can be seen in the table 3-15. The number of objects of each elements should be minimised to maximom 6 parts according to the kilometer of the tunnel by using the sweep method during 3D desining. Having too many objects can be time taking and confusing and not applicable.

Elements	The number of 3D objects
Base of the tunnel	831
Concrete layer above the floor	423
Ditch	806
Drainage side	804
Drainage backfill	807
Concrete slab	806
Ballast of sleeper part	800
TK system	284

Table 3-15 the number of existing objects of each element

Socondry, if only carbon emission of the concrete elements, without considering the equipment and tools, is needed, it should be more applicable to use more general 3D geometries with less level of development.

Finally, it should be bear in mind that the quality of the data is vital part for being able to minimize it. When it came to setting up the database, missing data from the export and import necessitated further rounds. When a set of geometries required to be assigned to the same task in Synchro, the user would often do so by manually choosing the relevant objects. As a result, there have been instances where one component or a small group of objects was left out when the entire group was assigned to a task. Therefore, during the assigning tasks, being sure about the completeness is necessary. Avoiding dublication of the geometries also is vital. This could be the result of a subset of the data being imported twice into Synchro.

4 DISCUSSION AND CONCLUSIONS

Summary of the study

In this study, firstly the existing gap is investigated after considering various research about 4D technologies. As it has been proved, although there are a vast number of studies about 4D scheduling, the number of data needed for scheduling has not been defined. Furthermore, it is proved that 4D BIM can be a functional way of simulation and calculating carbon footprint. In the next step, the case study chosen was a railway tunnel in both countries Slovenia and Austria. The case study is introduced and the majority of existing data was extracted from the case study. All elements and spaces were defined. It is proved some factors having accurate coordination and procurement are the base of the scheduling. Subdividing all the elements is one of the most important parts that should be taken. Taking this into account, the project is a summary of its sub-elements. The meaning of the sub-elements is crucial since it determines how the project will be carried out in the field. As it can be seen, for the scheduling the following rules should are considered:

- Gather all baseline data for a 3D model. Modelers should be sure that the model follows some criteria such as preparing and developing for the determined purpose, includes current LOD level and includes key data and components.

- Verify that 3D models are accurate for the parameters that are required.

- Add construction scheduling to the 3D model. To establish connection between 3D model and Schedule it should be noticed that although 3D models can have several LOD levels, 4D models can be modeled with less details and little representation. In fact, a 4D model can help compartmentalize detailing by grouping objects, site models and other items.

After creating the 4D model, the LumenRT tool is used to connect the 4D model to VR glasses to optimize the modeling. For controlling the data, following rules should be considered.

- Carefully define all elements and space definitions.

- Use standardized categorization

- Divide large files into several files

- Having comprehensive information about the model

- Organizing the model elements

- Organizing the elements according to the model plan. It helps to link elements to the activities effectively.

- Dividing the model element

It is also mention that the workflow also consists of creating or modifiying the model in Revit, in case it was needed to model demolish parts of the tunnel. For using point cloud also, several software such as Context capture and Autodesk ReCap are used to import it in to the LumenRT software.

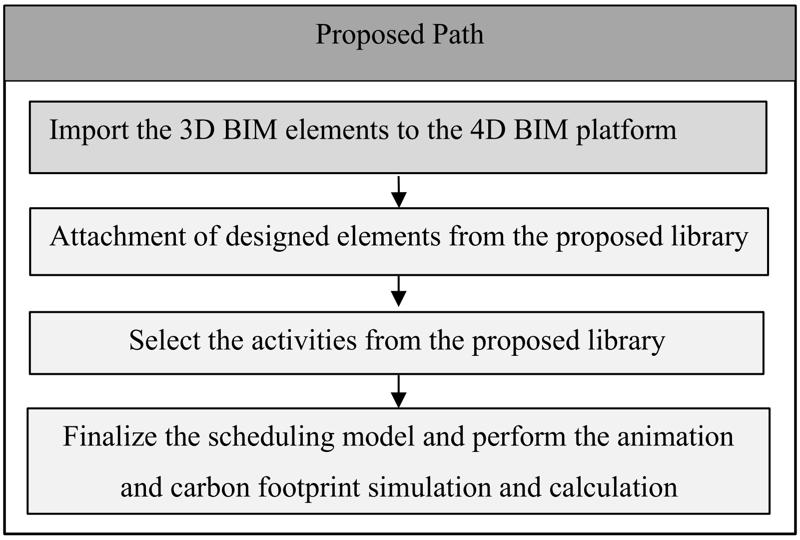


Table 4-1: The poroposed framefork of this study

What are the benefits

In the development project, the absence of data needed for the dynamic and keeping up with the smooth running of the venture is the most serious issue. Most of the stakeholders refuse using 4D BIM planning due to the fact that they are not able to manage the data. Moreover, since big projects such as tunneling have a huge amount of data, there are more possibilities of making mistakes and wasting time and money. The study addresses the problem of facing too much data for doing 4D scheduling. Finding a framework to address and manage the enormous amount of data in more complex models can be highly beneficial for construction stakeholders. Proposed library can be used by planner to creat the basic list of required activities for tunneling. This study also shows that 4D planning can be a practical way for calculating carbon emission. The carbon emission can be checked visually in the pre-construction stage and it can be decreased through proper management. It also is seen how 4D and the calculation of carbon footprint can be done by applying minimum data. This study also shows how 4D planning can be highly beneficial for different co-builders in construction projects.

What are the limitations

Although using 4D BIM can be highly beneficial, during this study some limitations has been recognised as followed:

- IFC is not able to keep all the essential data and some data will be missed through exporting and importing IFC files.
- Coordination of the model is the crucial part of the 4D scheduling. As the model was huge and it has too many objects, some parts of the projects have not been coordinated properly. Therefore, for solving this problem, several IFC files have been created which lead to creating too much data.
- For calculating the exact amount of carbon emission of the concrete, the information of companies providing concrete and their distance and the number of machines which have been used to deliver the material are essential. Due to the fact that there was not any information about the companies providing the concrete, this part of the study is ignored.
- This study did not fully apply on a live tunneling project, therefore more work would be required to expand on it and provide additional direction on how the various aspects of the framework could be applied in a 4D simulation.

What would you propose for the future

This study tries to improve the result in the 4D model by minimizing used data and providing more accurate and more realistic simulation. As it proved, using 4D planning can be the best tool for calculating carbon emission. Therefore, future development could take the framework as a basis and use 4D planning for calculating carbon footprint by providing minimum data. Machines, the critical path, equipment and the worker places can also be simulated via 4D planning to minimize carbon emission by avoiding rework.

Considering the current development of the IFC schema for infrastructure, more effort should be done to increase the elements type in the tunneling.

Another issue that should be tackled in the future could be the advancement of software tools. According to the research, none of the 4D applications on the market can shift temporal stages. Actually, there are several temporal stages in the simulation that should be overcome in the future to minimize the error and issues

5 ACRONYMS AND APPLICATION

3D: 3-dimensional

4D: 4-dimensional

BIM: Building Information Modelling

LOD: Level of Development

IFC: Industry Foundation Classes

LOI: Level of Information

WBS: Work Breakdown Structure

E&C: Engineering and Construction

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