Working Title: An OGC 3D tiling technique based user-interactive platform for digital twins in a virtual reality environment.

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1. Introduction

With the advent of faster and better processing power of computers, Internet of Things, and Big Data, in the past decades, we have seen a boom in the number of smart city projects undertaken for various cities throughout the world. This onset of focus on smart cities has also brought about a lot of digitisation of urban datasets, capturing of these datasets using sensors placed across the city as well as visualisation of the raw or analysed data onto visualisation platforms. While in the field of manufacturing and space applications, simulations as well as digital twinning of complex processes have been used for better analysis and decision making for a long time with the first instance being traceable to the NASA Apollo 13 mission (Cureton & Dunn, 2021; Ferguson, 2020; GlobalData Thematic Research, 2020), recent advances in technology as well as the conception of smart cities have enabled the these digital twinning of smaller process to be scaled up to a larger, urban scale.

In the field of urban planning, 3D models have been in use for some time to represent the physical form of the city by giving a visualisation of the physical elements of the city, they have also been employed and developed for use cases of disaster management, energy demand analysis, infrastructure planning, urban heat island analysis, etc (Biljecki et al., 2015)

An urban digital twin is a virtual representation of the real city, with all the real-time datasets being analysed and reflected at one single platform (Shahat et al., 2021). This platform can then be used by different professionals involved in the process of urban planning to take effective and well-informed decisions for the cities (Shahat et al., 2021). While in recent years, such platforms have been developed, they have mostly been used as a tool for visualisation of cities in 3D, however, in addition to usage of such platforms for the purpose of visualisation, it could be used to implement or develop a scenario analysis platform. This scenario analysis platform could then be employed in different use-cases of urbanism.

The 3D city models in itself can be quite large in size, for example, the CityGML file for the city of New York has a size of 590 MB (Ledoux, 2019), while there are researches in the field of 3D city models to reduce their size, like the OGC standard of CityJSON (Ledoux et al., 2019), the file size still remains quite large to be downloaded on the client side. Countering this problem of large city models, in 2019, OGC accepted and published, a 3D tile standard for streaming and rendering massive 3D geospatial data , this 3D tiling technique would be used for the visualisation of the 3D city models on the platform (Open Geospatial Consortium, 2019). The tiling standard ensures that large datasets have the capability for streaming them as 3D tiles, thus the client device only needs to render a small part of the visible frustum of the city model and not the entirety of it, only tiles which are visible are loaded.

1.1 Scope and Objectives

The scenario analysis platform, by its virtue, should be able to run user-interactive simulations on the city model and make the visualizations possible. Some of these simulations could be: traffic simulations in case of change of land use, or, neighbourhood development simulation, with the possibility for the user to change and define the floor area ratio, types of building, circulation pattern, ground coverage, urban population density, housing density, etc. This study will focus on the development of a user interactive platform for neighbourhood design with possibility to visualise and use the platform using virtual reality (VR).

The platform would be developed in a gaming engine, e.g. Unreal Engine, which would also allow us to make a more immersive experience for the end-user (by using VR or AR). The VR enabled platform is of use case in urbanism, especially so in the case of public participation or decision making, by enabling the end users to experience the proposed design using virtual visualisations.

This research could be taken into many directions, however, it will solely focus on the development of the platform, this would not be a research on finding the most optimised type of tiling technique that could be incorporated, or a research on how effective is VR platform for the purpose of urban designing as compared to traditional CAD, or a research on automated designing of an urban neighbourhood. These topics can be researches on their own and can be considered as future scope of the study.

1.2 Research questions

The main research question for this thesis is: **"To what extent can we make a combination of existing 3D city datasets with a user interactive neighbourhood designing platform in a virtual reality environment?"**

In order to attain the objectives specified in the above subsection, the following research sub-questions need to be addressed:

- In the use case of urban neighbourhood design, how can dynamic user selected designs be effectively visualised?
- Can the 3D tiling technique be utilised for the use case of urban neighbourhood development? And how can user-designed neighbourhoods be dynamically disseminated in the form of 3D tiling to incorporate it with the rest of the contextual 3D tiles?
- Is there a performance difference of the 3D tiling between LoD1 and LoD2 buildings in both: the user designed neighbourhood, and the contextual 3D city model?

2. Related Work

2.1 3D city models

City models are representations of the urban environment and the urban entities of the real world geographic locations (Billen et al., 2014). A 3D city model is a city model represented with the three dimensional geometries of the urban fabric which include the buildings, landscaping elements and other objects (Biljecki et al., 2015).

In the past decades, there have been many use cases of 3D city model, but mainly focusing on visualisation of the urban environment (Chen, 2011; Kolbe, 2009). With the improvement of GIS standards and simulation models, the use cases of 3D city models have also increased. This rise in the number of usage can be seen ranging from the fields of environmental simulation to urban planning, which deal with the problems faced in the urban environment like traffic network simulations, disaster management etc (Biljecki et al., 2015).

In the field of urban planning, 3d city models could help planners to visualise and simulate the urban environment to their understanding, and to see how things would differ if a certain plan were to be implemented versus another plan. This enables the possibility to interact with design choices (Chen, 2011) and then do scenario analyses based on the different simulations produced from the large urban datasets (Chen, 2011; Stojanović et al., 2014). In some studies such as those by Al-Douri, 2006; Onyimbi et al., 2017 3D city models are also shown to be stepping stones towards better and more inclusive public participation as it helps the common citizen to better comprehend the changes that would be brought about by certain policy changes or design changes to the city (Chen, 2011).

2.2 Digital Twins and Urban/City Digital Twins

The term Digital Twin was coined by Professor Grieves in 2003 in his lecture at the University of Michigan, however, the idea of twinning of physical processes so as not only to simulate pre-existing conditions but also to adapt the simulation to rapidly changing conditions digitally had already existed and could be traced back to as early as NASA's Apollo 13, where computational simulations could be run in real time to make strategic decisions following mid-flight failure of components (Ferguson, 2020). These digital simulations enable the user to assess performance of certain tasks using "what-if?" scenarios, improvements can be made to the product in a virtual environment and further tests can be conducted on the same, virtually (Ayres, 2012).

It is now possible to scale up this idea of digital twinning of processes to a scale of entire cities, to establish entire nations cities digitally (Rogers, 2019). Although this has been around for some years, it is still in a nascent stage of development. City or Urban digital twins can be said to be an evolution of Internet of Things and smart city concepts, emerging from a mixture of geographic information systems (GIS) and building information modelling (BIM) (Laat & Berlo, 2011). This fusion of GIS and BIM has many benefits where complex urban management is facilitated by leveraging information modelling of BIM and networking of GIS. These city digital twins can be used to for testing of scenarios, improved decision making, operation, etc. While BIM and GIS have been integrated for some time, we now also have large scale 3D city models in LoD2. For the case of this study, we will use such a 3D city model and not BIM datasets, since the focus is on a city scale perspective and not on individual buildings.

2.3 Research on use cases of 3d city models

A very exhaustive list of possible analysis and visualisations with the help of 3D city models can be found in the research done by Biljecki et al., (2015), listing a wide range of possible use cases of 3D city models, mainly dividing them into two main use cases: (i)Non-Visualisation based use cases such as solar irradiation estimation, energy demand estimation, floor space determination, build typology classification, and (ii) Visualisation based use cases, such as: visibility analysis, 3D cadastre, visualisation for navigation, facility management, emergency response management, lighting and shadow simulation, flood vulnerability estimation, forest management, population estimation, etc. While these use cases are stated to be for the application of 3D city models, an urban digital twin will essentially use a 3D city model and display other datasets on top of it.

2.4 OGC 3D tiling technique

2D tiles have been in use for the purpose of displaying 2D datasets on a map at varying scale. Similar to 2D tiles, 3D tiles is an open specification developed for "sharing, visualizing, fusing, interacting with, and analyzing massive heterogeneous 3D geospatial content across desktop, web, and mobile applications" (Cesium GS Inc, 2020). 3D tiles are built on an open standard, glTF, which is an open source, royalty-free specification for efficient transmission, streaming and rendering of 3D assets by engines and applications. The 3D assets are minimized by glTF along with the runtime processing required for unpacking them. glTF also enables interoperable use of 3D content across different platforms (Khronos Group, 2017).

OGC 3D tiling lets the user use different tile formats (Cesium GS Inc, 2020):

- Feature table and batch table
- Batched 3D models (b3dm)
- Instanced 3D models (i3dm)
- Point Clouds (pnts)
- Composite tiles (cmpt)

Some projects which have made a 3D city model visualisation platform, for example:

Table 1 Previously implemented projects incorporating 3D city models

Website	Area	Details
https://www.3dbag.nl	The Netherlands	A team at the 3D geoinformation research group of TU Delft has developed a countrywide, up-to-date 3D registration of building which uses tile based viewing for its web-viewer (3D BAG, 2021).
https://3d.amsterdam.nl/	Amsterdam	The municipality of Amsterdam has developed a 3D model of the city of Amsterdam which allows for user interaction with the web-viewer. The dataset used is from 3D BAG, and the platform is developed using Unity (Geemente Amsterdam, 2021).
https://www.3drotterdam.nl	Rotterdam	Similar to 3D Amsterdam, maintained by Municipality of Rotterdam (Geemente Rotterdam, 2021).
https://3d.utrecht.nl/	Utrecht	Similar to 3D Amsterdam, maintained by Municipality of Utrecht (Geemente Utrecht, 2021)

In addition to these platforms, there has also been a project from Geodan which focusses at the conversion of PostgreSQL city datasets (PostGIS) to 3dbm for use in Cesium or in MapboxJS (Geodan, 2022).

2.5 Gaming engine and VR for urbanism

Over the past years, gaming engines have found usage in the simulation of different environments and ecosystems, such as planning of fire escape routes in an indoor model of a building, or simulation of the road traffic network of a city (Besuievsky & Patow, 2013; FU et al., 2021; Rüppel & Schatz, 2011), than just creation of cross platform games. One such application has been found in the case of urban analysis; case studies such as (ESRI, 2019; Indraprastha & Shinozaki, 2009) show the usage of gaming engines in visualisation of urban design projects in which the user can interact with the model, however some analysis can also be conducted on urban data using gaming engines, such as finding the historical path using network analysis (Vletter, 2019) or calculation of rooftop solar potential (Buyuksalih et al., 2017).

The usage of 3D city models in a gaming engine brings about possibilities for visual and non-visual use cases (Biljecki et al., 2015) such as: energy demand application, rooftop solar potential estimation, visibility analysis, dynamic scenario based urban design, urban heat island analysis, etc. As the user can interact with these models in a gaming engine, from a visualisation perspective, it also enables the urban planners to view the simulated changes, with better spatial awareness and understanding to take better design decisions (Indraprastha & Shinozaki, 2009). The game engine enables for the study to incorporate some of its powerful features such as game physics, which make simulation of urban environments look realistic as well as better rendering capabilities for large 3D datasets, thus proving to be highly advantageous to our use case.

3. Methodology

3.1 Data collection

The data to be collected for this thesis is mostly obtained through secondary literature and pre-obtained or processed datasets such as those from 3D BAG (3D BAG, 2021), water bodies dataset, road network dataset, tree dataset. These will be collected from publicly available webpage for each of the resource, some of them being PDOK, INSPIRE, and 3D BAG.

3.2 User interaction with 3d tiles

For the platform to be developed with user interaction, we need to be able to select tiles or 3D assets which are being displayed on the users' screen. This is made available by the 3D tilling with Cesium, as it lets the user select 3D assets by interacting with them (using a mouse click or through means of touch). 3D assets could also be filtered out or selected by means of their attributes Figure 1, or by selecting by intersection with another 3D feature, like larder tiles, as can be seen in Figure 2.

Figure 1 Selection of 3D asset by attribute

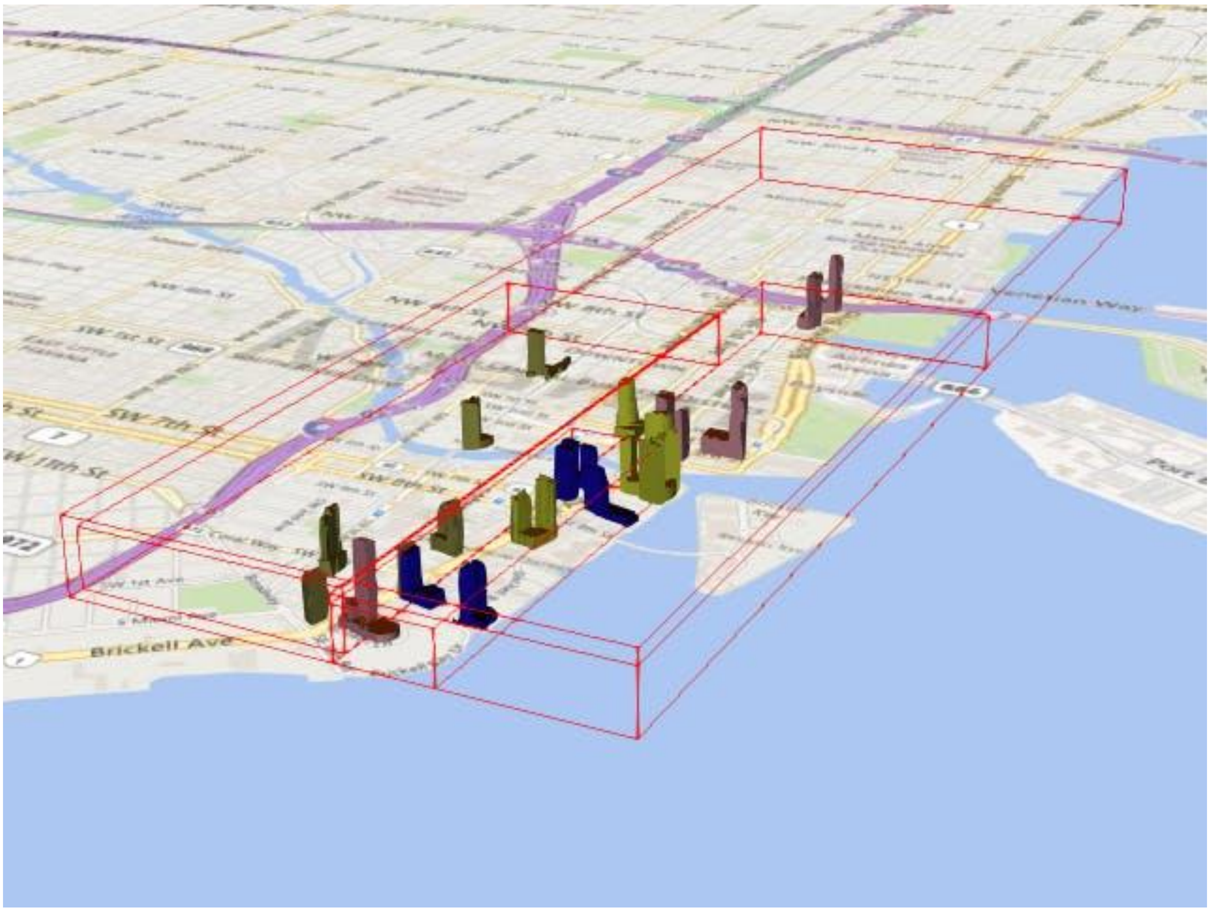


Figure 2 Possibility to select features by overlaying a 3D grid

Once a tile is selected, or a user defined area is demarcated, the 3D tiles in that area of interest could be cleaned, to display no data, so that a new neighbourhood could be developed on that spot using the platform.

3.3 Urban Neighbourhood development

The platform would be used for designing possible neighbourhoods at a delineated boundary set by the user. This would be achieved by letting the user select an area of interest following which the buildings and other 3D assets would be removed as per users criteria (if trees are to be removed or not). Since the neighbourhood design needs to follow a land use prescribed by the municipality, the dataset for the land use would be displayed on the now emptied land. The user would then be provided with options of types of buildings to place in the new neighbourhood, choose their built heights, additional landscaping elements and transportation network.

3.4 VR based visualisation

Since the thesis aims at creating an immersive experience for the user, VR needs to be employed. Cesium ion provides with APIs for usage of 3D tiles in Unreal engine (Cesium GS Inc, 2022), a summary of which can be seen in Figure 3.

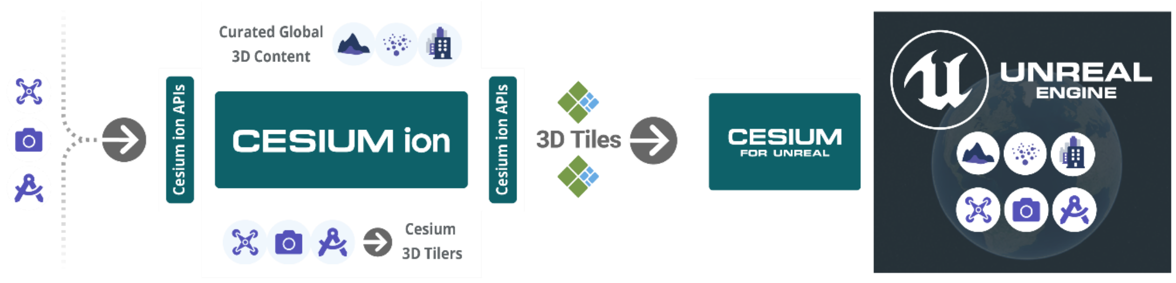


Figure 3 Cesium in Unreal

3.5 Performance analysis

For performance analysis of the developed platform at different LoDs, we need to see how this performance analysis is done for 2D map tiles. From Cadell, (2015); de Frutos, (2017), we see that the performance of 2D tiles can be checked in terms of the log data obtained from PostGIS, in the case of Cesium based viewing, we can log the number of tiles remaining to be loaded in a given amount of time for a given system and check the time performance of rendering of same tiles with different LoD buildings.

4. Tools and dataset

4.1 Tools

The tools that will be employed during the period of this thesis are culminated in the Table 2 below

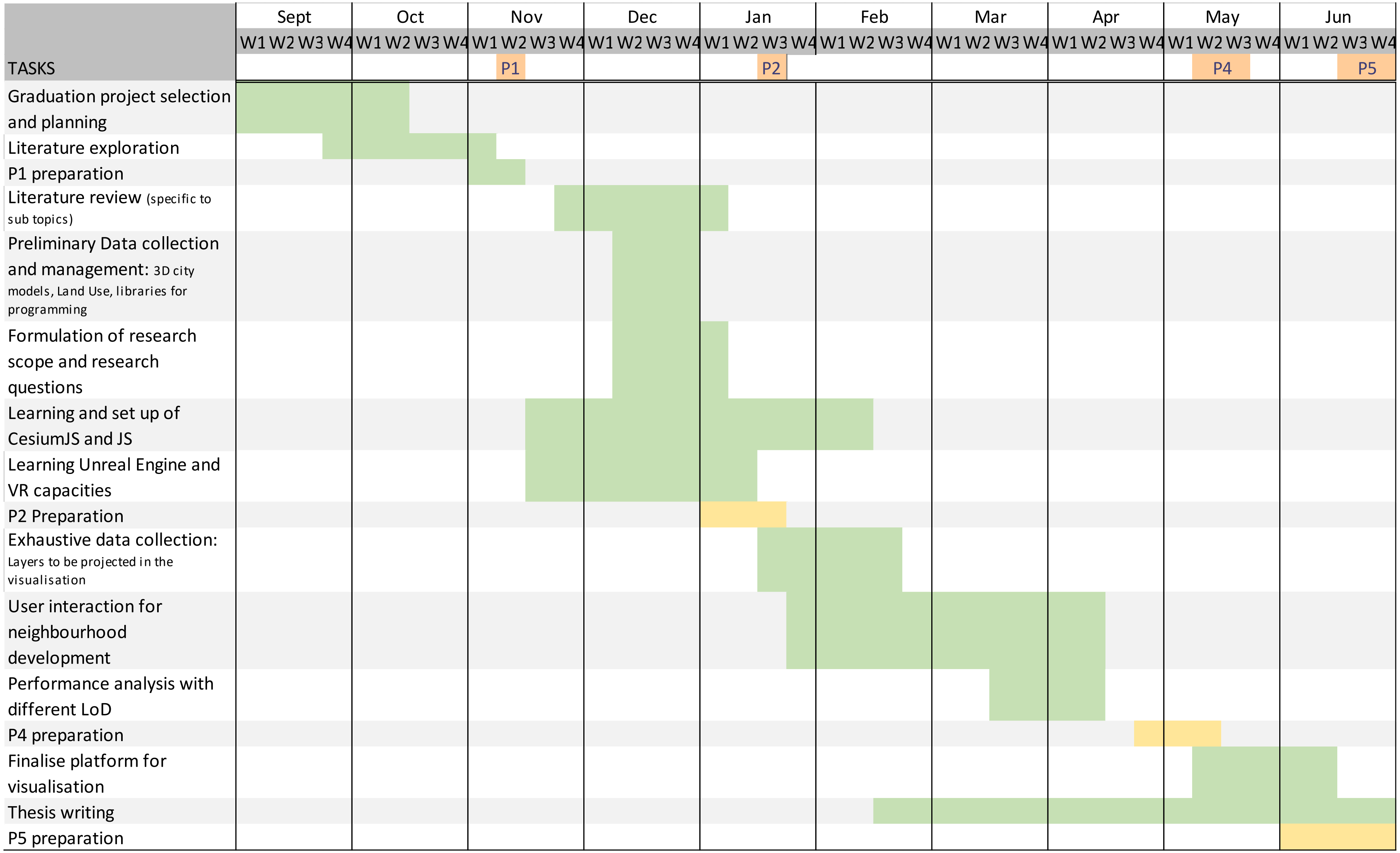
Table 2 Tools to be used for this thesis study

Tool	Usage
Programming Languages: JavaScript Python	CesiumJS is a JavaScript library that will be used for preliminary testing of deployment of 3D tiles, for which JavaScript is needed. Additionally, since Unreal engine will be used for visualisation, Python will be employed for running urban analysis on the 3D city dataset.
pg2b3dm	For conversion of PostGIS files to b3dm file format.
Gaming engine	For the visualisation of the platform, VR will be employed, hence, a gaming engine, Unreal Engine, will be used for the visualisation.

4.2 Datasets

The datasets needed for this project are mainly urban datasets and 3D assets, for example, the 3D city model for the country of Netherlands, which can be obtained from 3D BAG, the Land Use information from the ruimtelijkeplannen.nl, meteorological sensor information which can be obtained from the Ministry of Infrastructure and water and Municipal tree dataset from PDOK.

5. Time Planning



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