Graduation Plan

Delft University of Technology

GIS Technology Group

3D Integration in a Web GIS for Supporting Decision Making in Life Cycle Asset Management

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1 Introduction

Infrastructure assets like civil constructions, utility networks, roads, green areas, and lighting are managed by governments and municipalities and are characterised by relatively long service life. Therefore, a regulated approach for their long-term management is required. In that sense, the purpose of Asset Management (AM) is to keep a systematic record of the individual assets, plan maintenance, and implement appropriate information systems for facilitating the entire management process (Cagle, 2003).

Life Cycle Asset Management (LCAM) is an integrated approach for improving the decision-making process in each phase of the asset life cycle (planning, design, building, operation and maintenance, monitoring, disposal and recycling). In order to ensure efficient management, it is necessary to include the business processes, supporting resources, available data and technologies to the concept (Life Cycle Engineering, 2015).

In the last few years, there has been an increasing growth in the development of geographic information systems (GIS) due to the necessity for the acquisition, storage, manipulation, and visualization of spatial data. GIS are primary used for mapping, but they also facilitate performing complex spatial analysis and creating 3D models of the built environment (Scianna, 2013). The development of various GIS has significantly improved the operation in LCAM by enabling advanced data management and visualization. Previously, the public space management was based on simple tables and reports, which limited the data analysis possibilities (Makkonen, 2016).

Recently, the capabilities of GIS have expanded to complex spatial analysis and 3D visualization due to the increasing need for 3D geoinformation in urban planning, cadastre, environmental monitoring, landscape planning, and infrastructure and utility management (Zlatanova et al., 2002). Along with the development of 3D GIS, the planning and construction phases of AM are moving towards 3D modelling of the public assets as well (Makkonen, 2016). The methods in AM are diverse and depend on the life cycle phase. Moreover, there are differences in the approaches due to the stakeholders involved in the process. This project focuses on the 3D visualization of infrastructure assets in the maintenance phase by investigating how the 3D models created for design and construction should be adjusted to retrieve information required for practitioners and field workers responsible for maintaining the assets.

There are various sources of 3D spatial data suitable for different applications. Semantic 3D models like CityGML and Building Information Models (BIM) are suitable for data visualization in AM due to their high detail level. CityGML is an OGC standard for the representation and exchange of 3D models. The semantic-rich model provides a description of the geometry, topology, and semantic properties of various 3D urban objects, such as buildings, traffic infrastructure, city furniture, water bodies, etc (Prandi et al., 2015; Makkonen, 2016). BIM is a 3D-based computer model that contains essential information about the geometry and topology of an object and details about its construction, management, operations and maintenance (Makkonen, 2016). Both CityGML and BIM models will be handled in this graduation project.

The goal of this project is to incorporate 3D models of public assets in a Web GIS for optimising dynamic and complex processes in LCAM. Thereby, the problems and challenges in collecting, storing, and visualizing 3D spatial data will be presented and potential solutions will be provided. As an end product, a 3D prototype containing 3D models of civil constructions and additional information about them will be developed by using WebGL, a JavaScript API for web rendering of interactive 2D and 3D objects without the need of plug-ins. The prototype aims to facilitate a better visualization and management of the public assets, especially in the maintenance phase.

The graduation project will be made in a cooperation with Sweco Netherlands, a leading engineering consultancy company that is active in the fields of architecture and construction of smart cities. The test environment for building the 3D prototype will be a GIS web application for public space management *OBSURV* developed by Sweco. It is used by Dutch municipalities, provinces, and several private organisations and enables asset managers and decision makers to view and manage their assets. Currently, the visualization functionalities are limited to 2D only. Therefore, the integration of 3D models will be beneficial for providing a more realistic representation of the assets and performing potential analysis of the interactions with their environment. The Municipality of Rotterdam will be taken as use case for creating the 3D extension due to their interest in 3D visualization of the public assets. Their requirements will be specified based on interviews with experts in 3D geoinformation and AM. After completing this project, the users will be able to utilise the prototype for viewing and managing their assets in a more efficient way by retrieving essential information from the 3D models.

This project involves stakeholders from TU Delft, Sweco Netherlands and the Municipality of Rotterdam. The academic supervisors are Drs. Marian de Vries (first mentor) and Prof. mr. dr. Hendrik Ploeger (second mentor) who work closely with the student to complete the graduation project and provide consistent feedback about the skills and work quality. The mentor from the company is Hilbert Davelaar who should monitor the progress and ensure that the student is working for the company's preferences. To meet the key requirements of the main client, consistent contact was kept with the stakeholders and other experts.

2 Related Work

In recent years, the integration of 3D models in Web GIS has been extensively researched in diverse fields. The majority of the studies focuses on the creation of 3D city models based on CityGML data. Schilling et al. (2016) presented an approach for the efficient streaming of large and highly detailed CityGML models using WebGL (see Figure 1). The 3D buildings and other 3D urban objects were visualized with Cesium, an open source JavaScript library for creating 3D globes and maps. In their research, the glTF format was used for encoding the CityGML data and 3D Tiles for streaming the 3D datasets. Both glTF and 3D Tiles are adopted by Cesium for the efficient web rendering of 3D city models.

Figure 1: 3D city model of Berlin developed in Cesium by Schilling et al. (2016).

A similar research was conducted by Prandi et al. (2015) who developed a web viewer for storing, analysing, and visualizing large CityGML models via web using WebGL technology (see Figure 2). In their work, they presented a method for accessing huge datasets through web services by separating the geometric and semantic parts of the models. The geometries were visualized using Cesium, and the semantic information was retrieved from the database with the WFS service.

Figure 2: Web viewer created by Prandi et al. (2015).

Chaturvedi (2014) developed a web-based application for visualizing virtual 3D city models and performing 3D buffer analysis using WebGL. He built a decision support system for emergency situations that can be utilised by decision makers and field workers for evacuation planning. The web viewer was created with Cesium due to its extensive libraries that support 2D and 3D geometries and its ability to visualize dynamic spatial data. The author implemented algorithms for the on-the-fly generation of 3D buffer zones around the affected buildings (see Figure 3).

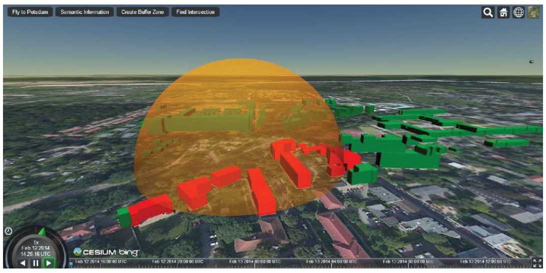

Figure 3: 3D buffer analysis viewer developed by Chaturvedi (2014).

Regarding the use of 3D models for optimising the decision making in AM, Makkonen (2016) conducted a research about the integration of semantic 3D models in AM. In her work, she made a review of existing practices for creating and maintaining 3D models using commercial and open source software and investigated the benefits of 3D models in the management of public infrastructure assets based on the interviews with experts in the field. According to the author, appropriate software solutions with proper data visualization are missing, although the need for integrating 3D models is increasing.

Boanca (2014) investigated the possibilities for integrating BIM models of civil constructions in OBSURV for a better public space management. In her thesis, she presented an approach for simplifying a detailed BIM model through geometric transformation and semantic mapping in order to provide the required information for the maintenance phase. The simplified model was stored in the Autodesk 360 cloud and linked to the web environment via URL link, which makes the model accessible on any device (computer, tablet, mobile phone). As can be seen in Figure 4, the functionalities of the developed prototype were limited to visualization only without allowing the users to edit additional information about distinct parts in the model. Moreover, the BIM-GIS integration requires further investigation, as there is no official standard yet.

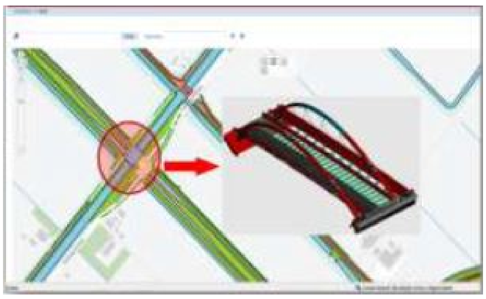

Figure 4: BIM model integrated in OBSURV Boanca (2014).

3 Research Questions

The graduation project will cover a broad research scope including the collection, storage and visualization of 3D spatial data. The main objective of the project is to investigate the available sources for obtaining 3D geoinformation for LCAM and the most suitable web rendering techniques for visualizing the 3D models. In the course of the project, the following research questions will be answered:

1. **What is the added value of 3D to LCAM?**
   1.1. What is LCAM?
   1.2. What is the current state of data visualization in LCAM and how can it be improved?
2. **How can 3D models be integrated in a Web GIS?**
   2.1. What are the user requirements for the 3D application?
   2.2. What is the most appropriate source of 3D spatial data of public assets?
   2.3. How can 3D models be stored and visualized efficiently in a GIS web application?
   2.4. What are the client and server side strategies for achieving optimal results?

Initially, it is necessary to understand the meaning of LCAM and the processes involved. Within the scope of this project, it is essential to investigate the current practices of visualizing the public assets in order to determine the potential improvements.

With respect to the integration of 3D models in a Web GIS, it is crucial to collect and analyse the user's functional and technical requirements for developing the 3D prototype. Furthermore, the most suitable source for obtaining 3D data for civil constructions will be given based on the research results. Afterwards, an approach for storing and visualizing the 3D models will be presented. Additionally, performance-improving strategies for achieving optimal results will be provided.

4 Methodology

The user requirements play a major role in the 3D integration for finding an approach to the desired solutions. Therefore, functional and technical requirements were specified based on interviews with AM advisers at Sweco Netherlands and experts at the Municipality of Rotterdam. The functional requirements define the development process of prototype by identifying the necessary tasks and activities that must be accomplished for obtaining successful results. The following requirements were specified by the stakeholders:

- Collection of CityGML and BIM models of public assets in Rotterdam
- Processing, storage and integration of the CityGML models
- Processing, storage and integration of the BIM models
- Prototype development according to the stakeholders' requirements
- Prototype quality assurance and testing
- Prototype improvement (if needed)
- Scalable solution to enable the implementation of the 3D prototype in the near future

The technical requirements address the system operation in terms of architecture, development, and deployment. The company and the main client have provided a rough list of requirements regarding the design and functionality of the 3D prototype:

1. **Sweco Netherlands:**
    - Visualization of the 3D models in separate windows
    - Rotation and zoom options for a better exploration of the 3D model
    - Showing additional information about the 3D model in the window
    - Selecting distinct parts in the 3D model and showing information about them in the window
    - Editing / updating information about the asset materials, measurements, placement date and documents
    - Colours assigned to the distinct parts of the 3D model according to the need for maintenance
    - Colours assigned to the 2D objects in the map according to the need for maintenance
    - Using hyperlink to connect the 3D model to the 2D object in the map
2. **Municipality of Rotterdam:**
    - Visualization of the 3D models in separate windows
    - Generation of a 2D base map for a better navigation in the window
    - Rotation and zoom options for a better exploration of the 3D model
    - Showing information about the 3D model in the window

- Selecting distinct parts in the 3D model and showing information about them in the window

It is visible from the list above that some of the technical requirements are given by both parties. The main difference in the user preferences is the source of 3D geoinformation. The AM advisers at Sweco Netherlands suggested detailed BIM models as suitable 3D spatial data for obtaining essential information about the public assets. In contrast to this suggestion, the Municipality of Rotterdam proposed CityGML models for the 3D integration in OBSURV. Therefore, both CityGML and BIM datasets will be incorporated in the web application and their suitability for the maintenance phase will be compared. It is expected that BIM models are more appropriate for visualizing civil constructions than generic models like the CityGML models.

Within the project management, it is necessary to identify the killer requirements in order to ensure that the project will run smoothly. The killer requirements are crucial for the risk management, as they specify conditions that could pose a risk to the success of the project. In case of this graduation project, the following conditions can be defined as killer requirements:

- Difficulties in finding BIM models of public assets in Rotterdam
- Potential complications in generalising BIM models for the integration
- Problems with linking the 3D models to 2D objects
- Performance issues of the web application
- Delivering the tasks on time

After having specified the key requirements, 3D models of several bridges and lamp posts were collected from the Municipality of Rotterdam. With regard to the CityGML datasets, the geometry and semantics should be verified and the LoD needed in the maintenance phase should be specified. BIM models are usually very detailed because they are developed for design purposes. Thus, it is necessary to check the level of development of the provided data and reduce to a certain level to allow for efficient data visualization in the maintenance phase. Furthermore, the generalisation of BIM models is required to prevent from expected performance issues of the web application due to the data size. Consequently, the 3D models should be stored efficiently. The CityGML models can be stored using 3DCityDB, a free CityGML compliant 3D geo database for managing and representing virtual 3D city models. The BIM models will probably be saved in the cloud via URL link.

The new version of OBSURV that will be released in 2018 consists of separate modules, each of them composed of different public assets, e.g. roads, green areas, playgrounds, underground infrastructure, etc. The module used for building the 3D prototype will be civil constructions that is not developed yet. Therefore, the web environment should be prepared for the 3D integration by developing the module in a similar way as the other OBSURV modules. Additional tabs for the 3D models should be added to the user interface (see Figure 5).

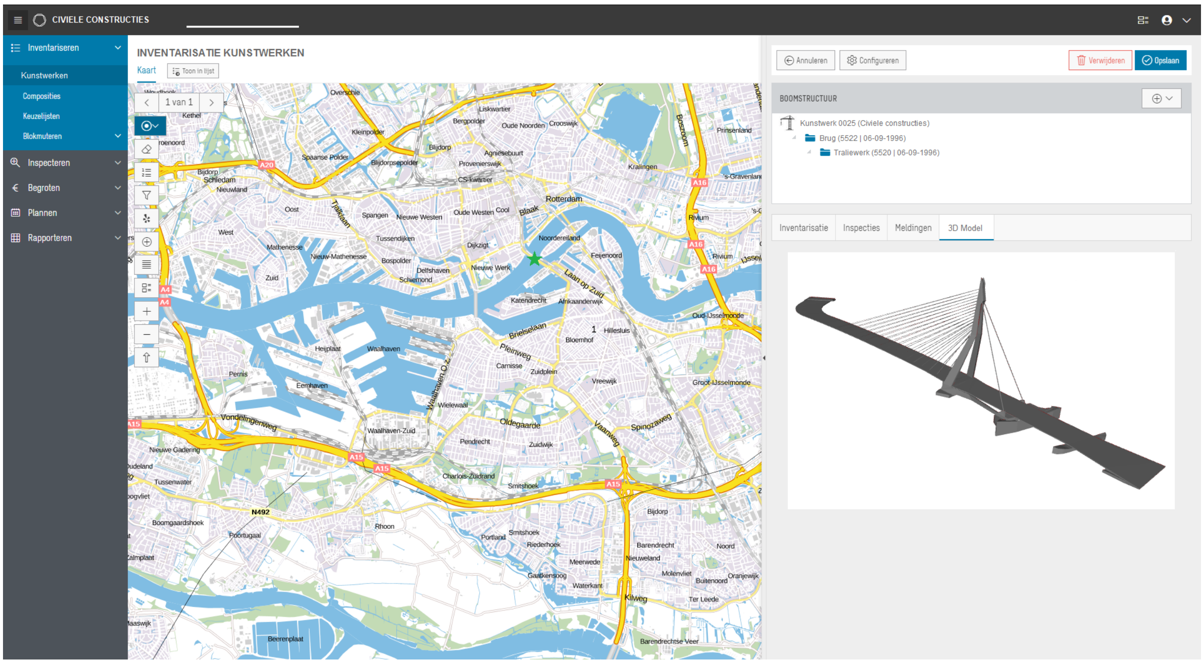

Figure 5: Draft user interface of the 3D prototype.

The integration of the processed 3D models will be done using WebGL libraries. First, the 3D data should be linked to the corresponding 2D objects in order to be easily accessed by the users. This can be achieved by using the object ID. Afterwards, separate windows showing the 3D models will be added to the user interface and designed according to the user requirements. As CityGML models are primary meant for data exchange, it is necessary to convert them to more efficient formats for web visualization, such as KML and/or COLLADA. The majority of the BIM models are already saved as OBJ, KML, or COLLADA that can be visualized on the web without any conversions.

The prototype will be provided to a group of users for evaluation. Based on the feedback, conclusions about the integration of 3D models can be derived and the prototype can be improved further. The test phase will be beneficial not only for enhancing the developed prototype, but also for validating the performance of the web application.

5 Time Planning

The project planning is represented by a GANTT chart, which allows for running the project more smoothly by keeping track of order of the project tasks and any dependencies between them. The diagram below shows the estimated time for performing the distinct tasks in the graduation project (see Figure 6).

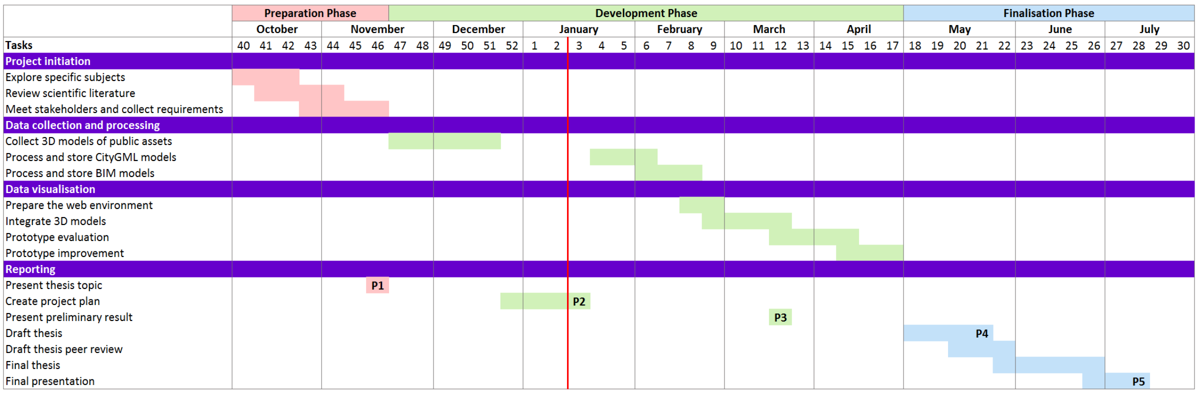

Figure 6: GANTT chart defining the time scale for each task in the graduation project.

There are three main phases in this project. The preparation phase includes a theoretical research and requirements specification. Initially, specific subjects related to the topic of the project were explored: 3D geoinformation and 3D web visualization. After having defined the key characteristics of the research topic, relevant scientific literature was reviewed to gain more knowledge and ideas of how to proceed and find the most suitable approaches for integrating 3D models in a Web GIS. Subsequently, meetings with the stakeholders involved in the graduation project were arranged to collect their requirements regarding the end product. The initiation phase was completed in seven weeks with a presentation (P1) that introduced the topic and objectives of the graduation project.

The development phase of the project consists of data collection and processing and data visualization. The acquisition of 3D models of public assets from the main client was extended to five weeks due to difficulties in finding appropriate BIM models for the research scope. After having collected the datasets, the CityGML and BIM models should be processed in order to provide the required information for the maintenance of the assets. Then, the 3D models should be stored efficiently and linked to the corresponding 2D objects. A project plan (P2) was created after collecting the 3D models to give a better overview of the graduation process. The data visualization stage includes the development of the 3D prototype and the integration of the CityGML and BIM models in OBSURV. Ten weeks are planned for completing these tasks. Afterwards, the progress will be presented in the mid-term presentation of the preliminary results (P3). Consequently, the prototype will be provided to other users for evaluation. Four weeks are scheduled for the assessment of the prototype so that the users will have enough time to test the 3D extension and give a feedback. The development stage is the longest project phase that lasts five months and needs to be accomplished a month before submitting the draft thesis.

The finalisation phase includes the reporting of the results. As can be seen in Figure 6, the draft thesis (P4) will be completed and presented after developing the 3D prototype for approx. four weeks. Meanwhile, the draft thesis will be given for a peer review to get a professional feedback on the thesis. In the end, the final thesis and presentation (P5) should be prepared for seven weeks.

6 Data and Tools

In this project, 3D models of bridges are the test data. The models were provided by the Municipality of Rotterdam as one of the stakeholders. The CityGML datasets were extracted from the 3D city model of Rotterdam. So far, no BIM models are collected, but they are expected soon specialists in the construction field. The following bridges were provided for integration in OBSURV: Erasmusbrug, Willemsbrug and Van Bienenoordbrug [1].

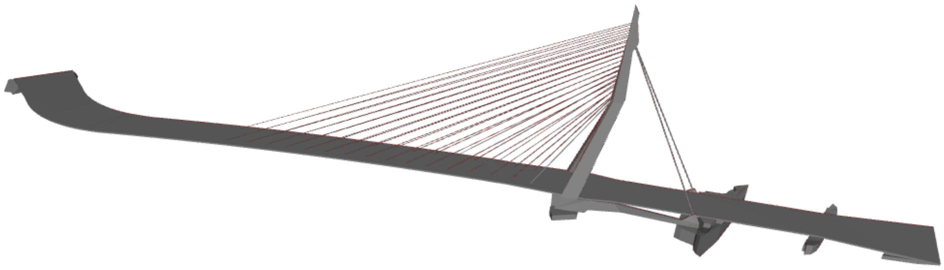

Figure 7: 3D model of Erasmusbrug.

Erasmusbrug is 802 metres long and located in the centre of Rotterdam and connects the north and south parts of the city (see Figure 7).

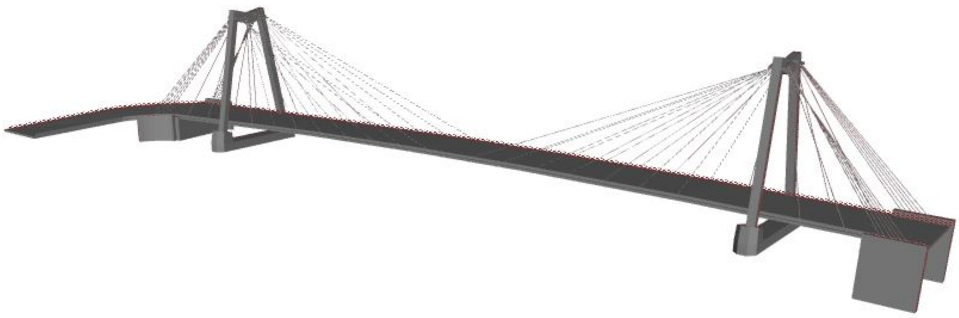

Figure 8: 3D model of Willemsbrug.

The 318 metres long Willemsbrug is built relatively close to the centre and links the island Noordereiland with the northern part of Rotterdam (see Figure 8).

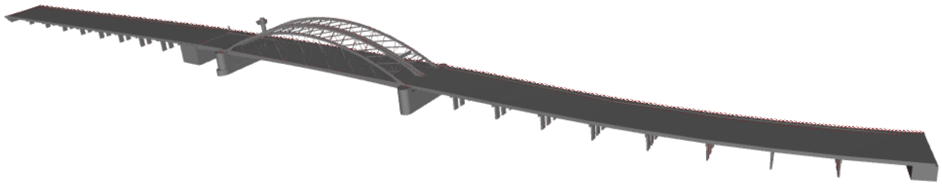

Figure 9: 3D model of Van Bienenoordbrug.

[1] brug = bridge (engl.)

Van Bienenoordbrug is a large bridge on the A16 motorway at the east side of Rotterdam. The bridge is the longest one from the provided bridges with a length of 1320 meters (see Figure 9). All three bridges cross the New Meuse, a major distributary of the Rhine river.

The tools used in the project are diverse, including commercial and open source software packages. The web environment will be prepared using Oracle APEX, on which the front-end design of OBSURV is based. As mentioned in Section 4, the CityGML models will be stored in 3DCityDB that will be implemented on Oracle Locator, the geo database management system in OBSURV. FME will be used for viewing and processing the 3D models due to its variety of transformers that can handle different formats. Additionally, the BIM models can be handled using other software programmes, such as Revit, SketchUp, Tekla.

There are several WebGL frameworks that can be used for the integration of 3D models in OBSURV:

- **Cesium:** JavaScript library for creating 3D virtual globes that enables fast visualization of dynamic spatial data (Chaturvedi, 2014).
- **Three.js:** JavaScript library for creating and rendering of 3D graphics due to its diverse functionalities.
- **Scene.js:** WebGL library for the simultaneous rendering of large number of objects that can be combined with Cesium (Chaturvedi, 2014).

There are two ways to visualize the CityGML models using the aforementioned WebGL techniques. The 3D datasets can be either encoded in glTF format and streamed with 3D Tiles in Cesium (see Section 2) or converted to KML or COLLADA and rendered with Three.js. The latter 3D library will be used for visualizing the BIM models due its ease of use and the variety of built-in functions for rendering complex 3D models.

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