

Project Title

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# ABSTRACT

An innovative combination of Geographic Information Systems (GIS) and 3D architectural models has characterised the progress of the built environment. The present dissertation discusses the challenges involved in integrating 3D building models formatted in Industry Foundation Classes (IFC) into the Cesium GIS platform. The study presents a methodical conversion procedure that makes use of the Web-IFC library, Three.js, and CesiumJS in order to overcome the difficulties presented by model fidelity, data formatting, and performance concerns. A thorough framework for managing IFC files, preparing them for online visualisation. Conversion times, file sizes, and model geometries are examples of performance measures that offer insights into the complex trade-offs necessary to achieve seamless integration. Comparative analysis of various building models underscores the nuanced relationships between fidelity and loading efficiency. The dissertation concludes with reflections on the achieved milestones, proposing avenues for future work, such as scalability improvements, real-time updates, and exploration of advanced compression techniques. Ultimately, this research contributes to the advancement of spatial data integration, offering a harmonious coexistence between 3D building models and GIS for enhanced decision-making in urban planning and beyond.

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# INTRODUCTION

As the utilization of 3D building models continues to expand for various applications, such as facility management and urban planning, the built environment is undergoing a significant transformation. It is evident that the integration of these intricate 3D models with Geographic Information Systems (GIS) is crucial (Suzana Dragićević & Munn, 2023), but there are numerous hurdles to overcome, primarily associated with the inherent differences in data formats. To address the intricate network of data formatting issues, this thesis will comprehensively examine the obstacles involved in merging 3D architectural models with GIS.

## BACKGROUND STUDY

In recent years, there has been a notable shift in the way that 3D building models are utilised, and they are now considered essential in many other areas, such as architecture, urban planning, and geospatial analysis. By encapsulating the geometric and semantic details of real structures, these models provide a thorough digital portrayal of the built environment (Biljecki et al., 2015). Typically, the Industry Foundation Classes (IFC) standard is used to express them. The more complex these models are, the more effective GIS integration is required, which results in a dynamic environment full of opportunities and difficulties.

Zhu et al. (2019) stated that inconsistent data formats are one of the main barriers to the integration of 3D architecture models with GIS systems. 3D architectural models are frequently arranged in formats like IFC, although GIS systems may handle a wide range of formats that are tailored for geographic data. A thorough understanding of both fields is necessary to narrow this gap, including coordinate systems, semantic richness in 3D models, and the subtleties of spatial data encoding.

The amalgamation of GIS and 3D building models has significant possibilities for transforming decision-making procedures in diverse sectors (Wang et al., 2023). The seamless synthesis of these technologies can reveal new layers of knowledge in a variety of fields, including urban planning, where the spatial interaction between buildings and infrastructure is crucial, and disaster management, where exact 3D representations can boost situational awareness. But achieving this potential will require overcoming the difficult obstacles posed by data formatting problems, which are the main focus of this study.

### MOTIVATION

This research is motivated by the realisation of the revolutionary potential that seamless integration of 3D building models with GIS may have across several industries. A comprehensive knowledge of the built environment is promised by the combination of the innate spatial intelligence of GIS and the intricate representations offered by 3D building models. Through this integration, decision-makers, architects, and urban planners may be able to see, evaluate, and optimise spatial combinations with never-before-seen capabilities (Al-Rawabdeh et al., 2014).

In addition, the existing gaps in technology and knowledge serve as a source of inspiration. The complexity of the integration process is frequently too much for the current approaches to handle, which threatens system performance or data integrity. By creating a thorough conversion method that guarantees the smooth integration of 3D models into GIS systems while also maintaining their integrity throughout translation, our research seeks to close these gaps (Singh et al., 2023).

In essence, this study seeks to contribute to the evolving landscape of spatial data integration, offering a nuanced solution to the challenges posed by data formatting issues. The ultimate goal is to pave the way for a harmonious coexistence of 3D building models and GIS, fostering a synergy that enhances our ability to comprehend and interact with the built environment in an unprecedented manner.

## AIMS AND OBJECTIVES

This study's main goal is to look at the difficulties in integrating 3D building models into GIS, with a particular emphasis on the intricate data formatting issues that prevent smooth integration. The particular goals are:

1. To carry out a thorough analysis of various data formats in GIS and 3D building models, comprehending their special traits and difficulties;
2. To be a trailblazer in the creation of a reliable conversion method to improve the interoperability of GIS systems and 3D building models;
3. To assess the amount of information that can be preserved while translating 3D building models to GIS;
4. To evaluate the effect of adding sophisticated building models on the performance of the GIS system, providing information about possible trade-offs and optimisations.

## SCOPE AND LIMITATIONS

This study's primary goal is to look at the difficulties that come with data formatting problems when combining 3D building models—especially those that are represented in the IFC format—with GIS. Additionally, a conversion method that guarantees smooth compatibility between the two systems is suggested by the research. The scope encompasses:

1. **3D Building Models:** The study primarily deals with the integration challenges associated with 3D building models, particularly those structured in the IFC format.
2. **GIS Systems:** The research targets GIS systems and their compatibility with 3D building models, examining diverse data formats used in GIS for geospatial data representation.
3. **Conversion Mechanism:** The proposed conversion mechanism focuses on bridging the gap between IFC-based 3D building models and GIS systems, ensuring efficient data transfer and interoperability.

While this research endeavors to make meaningful contributions to the integration of 3D building models and GIS, certain limitations are acknowledged:

1. **Data Formats:** The study primarily addresses challenges related to the IFC format for 3D building models. Other formats may present unique challenges not explored in this research.
2. **GIS Systems Variability:** The integration challenges discussed may vary across different GIS systems. The research focuses on generic aspects but may not capture nuances specific to each GIS platform.
3. **Conversion Mechanism Generalization:** The proposed conversion mechanism is tailored to the IFC-to-glTF conversion. Extending its applicability to other conversion scenarios might require additional considerations.
4. **Resource Constraints:** The scope of this study is bounded by the available resources, both in terms of time and technology. Comprehensive testing across all potential scenarios may be limited.
5. **Application Domains:** The findings of this research are primarily applicable to urban planning, architecture, and related domains. The extent to which these findings can be extrapolated to other application domains remains a consideration.

Despite these limitations, the research aims to provide valuable insights into the broader challenges and potential solutions associated with the integration of 3D building models and GIS, contributing to the ongoing discourse in the field.

## SIGNIFICANCE OF THE STUDY

This research endeavors to contribute to this evolving field in several ways:

### ADVANCEMENTS IN URBAN PLANNING

The seamless integration of 3D building models and GIS holds the potential to revolutionize urban planning processes. By providing a holistic representation of spatial relationships between buildings, infrastructure, and the surrounding environment, decision-makers can gain deeper insights (Billen et al., 2014). This contributes to more informed urban development strategies, optimizing resource allocation, and fostering sustainable, resilient cities.

### ENHANCED DISASTER MANAGEMENT

In the realm of disaster management, the accurate representation of the built environment is paramount. Precise 3D models integrated with GIS enable a more comprehensive understanding of disaster-prone areas, facilitating proactive planning and response strategies (Cao et al., 2023). This study aims to enhance situational awareness by addressing data formatting challenges, thereby contributing to more effective disaster management practices.

### EMPOWERING ARCHITECTURE AND DESIGN

Architects and designers stand to benefit significantly from the seamless integration of 3D building models with GIS. The ability to visualize and analyze spatial data in a geospatial context opens new possibilities for innovative design solutions (Wang et al., 2019). This research, by addressing challenges in data formatting, aims to empower professionals in the architecture and design fields to leverage spatial intelligence for creative and functional designs.

### INTEROPERABILITY IN SPATIAL DATA

The proposed conversion mechanism and insights gained from this research contribute to the broader discourse on interoperability in spatial data. By addressing challenges in the integration of diverse data formats, this study aims to foster a more collaborative and interconnected ecosystem. This has implications not only for the current landscape of 3D building models and GIS but also for future advancements in spatial data technologies.

## DISSERTATION SUMMARY

The main goal of this research is to overcome the difficult obstacles that arise from data formatting problems while integrating 3D building models with GIS. The process starts with a careful examination of the data formats that are specific to each domain, continues through the complexities of IFC files, and ends with the development of an advanced conversion tool. By utilising state-of-the-art tools like Three.js and the web-ifc library, the study converts IFC files to glTF format, optimises it with the glTF-Pipeline tool. The development of a frontend application, seamlessly integrated with CesiumJS, marks the culmination of this transformative process, enabling users to explore 3D assets in a geospatial context with unprecedented ease.

# LITERATURE REVIEW

This literature study delves into a number of topics pertaining to web-based GIS platforms, 3D building modelling, and GIS integration with building models. These studies offer insightful information about novel techniques and strategies that might improve data sharing, decision-making, and geographic visualisation. The literature review covers a wide variety of subjects, including the development of web-based GIS platforms for watershed management, the use of spatial ETL solutions for 3D building modelling, and the integration of GIS with building information modelling.

The literature review's first portion is devoted to 3D building modelling. The second segment explores web-based GIS systems and presents research that addresses the shortcomings of traditional platforms. The integration of building models with GIS is examined in the last subsection. Every research offers a different viewpoint on the subject, addressing issues, offering creative fixes, and highlighting the possible advantages of applying these approaches to geospatial and architectural information initiatives.

## 3D BUILDING MODELLING

The scholarly work of (U. Drescek, 2020) introduces an innovative approach that utilizes spatial extract, transform, load (ETL) solutions for 3D building modelling based on data from unmanned aerial vehicles (UAVs). The primary objective is to present a comprehensive workflow for 3D building modelling, highlighting the advantages of spatial ETL solutions. The paper addresses the challenges in generating 3D city models despite the growing demand for them. While traditional methods like aerial photogrammetry and airborne laser scanning are costly, UAV photogrammetry offers a more cost-effective and flexible solution. The authors employ a spatial ETL solution to reconstruct a 3D building model from a dense image matching point cloud derived from UAV imagery. The resulting models are consistent with the OGC CityGML standard, Level of Detail 2 (LOD2). The methodology was tested on selected buildings in a semi-urban area. The study concludes that spatial ETL solutions can be effectively used for 3D building modelling from UAV data. The paper's focus on using UAV data for 3D building modelling can be integrated into my project, for expansion of data sources. The use of spatial ETL solutions can streamline the conversion process from IFC to GLTF, ensuring that the models are consistent and accurate. Whereas the author (Chaoquan Zhang, 2021) delves into an interactive and cost-effective solution for 3D building modelling using street-level Volunteered Geographic Information (VGI) images. The research emphasizes the potential value of VGI3D for the 3D modelling community after testing with a limited number of expert and non-expert participants. Although the abstract provides limited details, it suggests that VGI3D offers a promising approach to 3D building modelling by leveraging street-level images, which can be a rich source of spatial data. The concept of using street-level images for 3D modelling can be an additional feature for the converter. By integrating such data, we can enhance the details and accuracy of the GLTF models that are loaded onto the Cesium map view. This approach can also provide a more immersive experience for users who wish to visualize buildings in their real-world context.

## WEB-BASED GIS PLATFORMS

A web-based digital twin platform is presented in the study by (management, 2022) in an effort to overcome the drawbacks of conventional digital watershed platforms. The platform seeks to give watershed management decision-makers strong assistance and a more accurate representation of geospatial components. The authors have created a thorough virtual simulation of geographic components by utilising a variety of 3D modelling techniques. They also created a browser-side data loading mechanism for 3D model cull rendering and dynamic loading. The platform also incorporates spatiotemporal modeling of multisource data, analysis of various data types, and scientific computation of mathematical models to support precise watershed management. The platform was applied to the Chaohu Lake Watershed, demonstrating its capability to provide both visually appealing and practical decision-support functions. Since my project geospatial visualization, this paper's methodology can be beneficial. The use of a digital twin platform can enhance the accuracy and realism of the GIS models in the platform. Comparatively, the project offers a different approach to geospatial visualization or focuses on other aspects of GIS, this paper provides a benchmark against which we can measure the project's unique features or improvements.

As we delved into the creation of a web-based model-sharing repository and a model-viewing application specifically for the EPANET modelling community. The author (Tylor Bayer, 2021) utilized HydroShare as the backend data store for the EPANET model program, model instances, and metadata. They also employed the Tethys Platform framework to develop a web-based front-end for the repository and viewer. The outcome of this work is a functional model repository and a lightweight model viewer application that encompasses most of the legacy EPANET desktop GUI’s functionality. The paper emphasizes the importance of sharing both model programs and model instances in the field of environmental and hydrologic modelling, and the presented platform serves as a solution to this need. As the project involves creating or using a web-based GIS platform for sharing and viewing models, the methodologies and tools presented in this paper can be of great value. The integration of backend data stores like HydroShare and frontend frameworks like Tethys can streamline the platform's functionality. On the other hand, the project offers a different approach or additional features, this paper can serve as a reference point to highlight what sets the platform apart.

## LINKING GIS AND BUILDING MODELS

In her extensive work, Laura Knoth (2016) investigates how GIS may be integrated with different domains, with a particular emphasis on exploiting spatiotemporal data to link smart factories to the outside world. This study highlights the critical role that spatiotemporal data plays in bridging the gap that exists between the physical world and smart factories. It emphasises how crucial it is to include building information in Enterprise Spatial Data Infrastructures (SDIs) in order to improve interior settings' contextualization. This makes it possible to comprehend interior settings in more detail in relation to larger temporal and geographical contexts. The study article, on the other hand, addresses the more comprehensive integration of GIS with diverse domains, with a focus on the significance of spatiotemporal data in linking smart factories to their actual environments. Furthermore, the author (Alyssa Huaqiu Liu, 2021) offers a thorough analysis of the benefits and technical considerations associated with combining 4D BIM and GIS for decision-making in building projects. This study report essentially emphasises the significance of integrating GIS with 4D BIM, which incorporates time into conventional BIM models, to improve decision-making during construction. It explores the possible advantages of this kind of integration, including enhanced project management, enhanced construction progress visualisation, and effective resource allocation. The article also discusses the potential and difficulties that come with putting this integration into practise, especially in the context of big infrastructure projects. My project focuses on data transformation, enabling the interactive exploration of 3D architectural models. In contrast, the research paper discusses the broader topic of integrating 4D BIM and GIS for decision-making during construction, showcasing the complexities and potential advantages of combining these technologies to optimize construction processes.

The goal of the project, "Knut Jetlund, 2020," is to improve the communication between GIS and Building Information Modelling BIM. By creating connections and harmonising fundamental information ideas that are essential to both fields, it seeks to accomplish this. Essentially, the goal of this research is to provide a bridge between BIM and GIS, acknowledging that although they may employ distinct schemas and standards, these two domains frequently deal with identical information. The project aims to provide a more smooth data and information sharing between BIM and GIS systems by harmonising the fundamental ideas and modelling them using ISO/TC 211 compliant UML (Unified Modelling Language). The research emphasizes harmonizing core concepts between BIM and GIS to enhance interoperability, while my project centers on creating and rendering 3D architectural models, showcasing the diverse ways technology can enhance different aspects of data management and visualization within the context of architectural and geospatial information.

### Augmented Reality (AR) Integration in Geospatial Visualization

The integration of augmented reality (AR) in geospatial visualisation is a rapidly developing discipline that is the subject of the literature study. The possibility of using augmented reality technology to improve the user experience when navigating and engaging with geographical data is explored in a seminal research by Jansen et al. (2023). The authors provide an augmented reality system that projects digital data into the physical world, giving users a contextually aware and immersive geographical experience. This integration has potential for applications in urban planning, navigation, and public engagement, in addition to making geographical dataset exploration more natural. Jansen et al. (2023) research reveals the transformative impact of AR on geospatial visualization by merging virtual information with the physical world. The study demonstrates how AR can be leveraged to present complex geospatial datasets in a user-friendly manner, allowing individuals to gain insights into their surroundings in real-time.

## Findings of Literature Review

Literature evaluation reveals a wide range of cutting-edge techniques and strategies in the areas of web-based GIS platforms, 3D building modelling, and GIS integration with building models. The research conducted by Drescek and Zhang provides insights into alternate resources and economical techniques for producing precise and comprehensive 3D models in the field of 3D building modelling. Drescek's focus on spatial ETL solutions based on UAV data presents a viable path to address issues with conventional approaches, and Zhang's investigation of street-level VGI images adds an interactive and reasonably priced element to 3D building modelling, enhancing the possibilities for immersive user experiences.

Solutions to improve geographic visualisation and data exchange are shown by the literature review's examination of web-based GIS platforms, especially the research by management and Bayer. The web-based digital twin platform that management introduced is notable for its ability to assist decision-makers in watershed management by providing a thorough virtual simulation of geographic components. With an emphasis on a model-sharing repository and viewer application for the EPANET modelling community, Bayer's work offers a workable solution for sharing model instances and programmes. It also provides insightful information for projects looking to improve user experiences and streamline functionality in web-based GIS platforms.

The research by Knoth, Liu, and Jetlund demonstrate that the integration of GIS with building models is an important issue investigated in the literature. The importance of spatiotemporal data in bridging the gap between smart factories and their environs is highlighted by Knoth's work, underscoring the necessity of include spatial data infrastructure. In order to improve decision-making in building projects, Liu's research explores the integration of 4D BIM and GIS, showing both the potential benefits and difficulties of doing so. By attempting to better communication between GIS and BIM, Jetlund's project adopts a novel viewpoint and highlights the significance of harmonising basic information concepts for improved interoperability. When combined, these results offer a thorough basis for comprehending and using state-of-the-art techniques in architectural and geospatial information initiatives.

# METHODOLOGY

## METHODOLOGIES FOR CONVERTING BUILDING MODELS TO GIS COMPATIBLE FORMATS

### OVERVIEW OF DATA FORMATTING CHALLENGES

The ability to successfully navigate a variety of complex data formatting issues is essential for the successful integration of 3D building models into GIS. The most significant of these difficulties is the disparity in data structures between GIS and 3D building models, which results from fundamental variations in the representation of geographical information. Resolving these fundamental differences is essential to accomplishing a smooth and compatible merger. A further degree of difficulty is added by metadata misalignments, as definitions might become inconsistent due to differences in metadata protocols between 3D building models and GIS (Zhu et al., 2018). To correct this mismatch, metadata structures must be carefully examined and methods for resolving discrepancies must be developed.

Inconsistencies in geometric attributes make integration even more difficult. Variations in coordinate systems, accuracy, or the depiction of intricate geometries may make it more difficult to accurately overlay data into GIS platforms (Wadembere & Ogao, 2008). Maintaining the data's geometric integrity depends on resolving these disparities. Guaranteeing structural compatibility necessitates taking a comprehensive strategy to align hierarchical structures, relational models, and thematic classifications within the datasets. This means that problems go beyond individual data items.

## SELECTION OF INITIAL CONVERSION TOOLS

In the initial phase of this research, a critical aspect involved the selection of appropriate tools for the conversion of 3D building models to GIS-compatible formats. Several tools were evaluated based on their capabilities, compatibility, and ease of integration into the existing workflow. The available tools ranged from comprehensive software solutions to specialized libraries designed for specific tasks within the conversion process. After careful consideration, the web-ifc library and Three.js emerged as the optimal choices for the initial conversion. The web-ifc library demonstrated versatility in handling IFC files, a prevalent format for representing 3D building models. Its capacity to efficiently parse and process IFC files aligned with the project's requirements. Furthermore, the library's ability to interface seamlessly with web-based applications made it a suitable candidate for integration into the overall architecture.

Complementing the capabilities of the web-ifc library, the decision to incorporate Three.js was grounded in the latter's prowess in 3D graphics rendering for web environments. Three.js provided a robust framework for creating interactive 3D scenes directly within a web browser. Leveraging the capabilities of both libraries, the initial conversion process was structured to load IFC files using the web-ifc library and subsequently transform them into the glTF format using Three.js's glTF exporter. This selection was underpinned by the rationale that combining the strengths of the web-ifc library, tailored for IFC file handling, with the advanced 3D rendering capabilities of Three.js would result in a cohesive and efficient initial conversion process. The tandem use of these tools aimed to strike a balance between the intricacies of 3D model representation and the requirements for GIS-compatible formats.

## DEVELOPMENT OF CONVERSION MECHANISM

The development of a robust conversion mechanism serves as the crux of the methodology, aiming to bridge the intricate gap between 3D building models and GIS. This sub-section discusses the intricacies of the conversion process, elucidating the methodologies, tools, and technologies employed to ensure a seamless and accurate transformation.

### 3D MODEL LOADING AND SCENE CREATION USING WEB-IFC LIBRARY

The initial phase is loading IFC files by utilising the web-ifc library's capabilities. This library makes it easier to retrieve important information from complicated building models by managing IFC data in web contexts in an effective manner. The imported IFC file is then dynamically used to construct a Three.js scene, which serves as a foundation for further manipulation and visualisation.

Figure 1 Proposed Methodology for Development of Conversion Mechanism

### TRANSFORMATION INTO GLTF FORMAT USING THREE.JS GLTFEXPORTER

The Three.js scene loaded via the browser ifc is converted to the glTF (Graphics Library Transmission Format) standard. This is an important step if you use the Three.js library's gltfExporter. Because of its lightweight design, web compatibility, and capability for 3D model representation, the glTF format is recommended. This conversion guarantees that the 3D building models' fine features are maintained while getting them ready for a smooth interaction with GIS.

### OPTIMIZATION USING GLTF-PIPELINE

To enhance the efficiency and performance of the glTF files, the glTF-Pipeline utility is employed. This tool plays a vital role in converting glTF files into the binary glTF (glb) format, promoting faster loading times and reduced file sizes. Additionally, the application of Draco compression through glTF-Pipeline further optimizes the files, ensuring an optimal balance between quality and performance during subsequent GIS integration.

### FRONTEND APPLICATION USING HTML

To provide users with a dynamic interface for accessing and visualizing the converted assets, a frontend application is developed using HTML. JavaScript library for building 3D globes and maps, is integrated into the application. This integration enables the retrieval of hosted assets from java liberary and their display in a geospatial context, allowing users to explore the 3D building models seamlessly.

## EXPERIMENTAL METHODOLOGY

There are several phases involved in the process, starting with importing IFC files using the web-ifc library and ending with transforming them into the glTF format. Every step is carefully laid out to guarantee that the experimental framework is fully understood.

### OVERVIEW OF THE EXPERIMENTAL FRAMEWORK

The overall structure that is used to evaluate the conversion process is provided by the experimental framework. It includes the choice of relevant measurements, the creation of test scenarios, and the overarching plan for assessing the conversion process's effectiveness.

* The first conversion made with the web-ifc library: The experimental methodology's first conversion phase, which focuses on effectively handling IFC files by leveraging the web-ifc library's capabilities, is crucial.
* Bringing up IFC Files: The web-ifc library is used to load IFC files at the start of the operation. In this stage, vital information about the building models is extracted by parsing the IFC file structures. The loading stage ensures that the fine features of the 3D models are faithfully captured inside the transformations that come after.
* Creating Three.js Scene: Once the IFC files are loaded, the next step involves creating a Three.js scene dynamically. This scene serves as the canvas for the subsequent visualization and transformation processes. The creation of a Three.js scene is crucial for providing a platform where the 3D building models can be represented and manipulated programmatically.
* Transformation into glTF Format: Building upon the created Three.js scene, the experimental methodology proceeds with the transformation of the 3D building models into the glTF format. This transformation involves leveraging the gltfExporter within the Three.js library. The glTF format is chosen for its lightweight nature and compatibility with web-based visualization tools. This step ensures that the 3D building models are translated into a format suitable for seamless integration into GIS systems.

## TEST CASES

The test cases selected for evaluating the proposed conversion mechanisms encompass a diverse set of IFC files, reflecting a range of sizes, complexities, and semantic attributes inherent in 3D building models.

Among the chosen test cases are "advanced\_model.ifc," characterized by its large scale and intricate geometric details; "clinic.ifc," representing a medium-sized medical clinic with specialized equipment; and "example.ifc," a smaller-scale model serving as a foundational example.

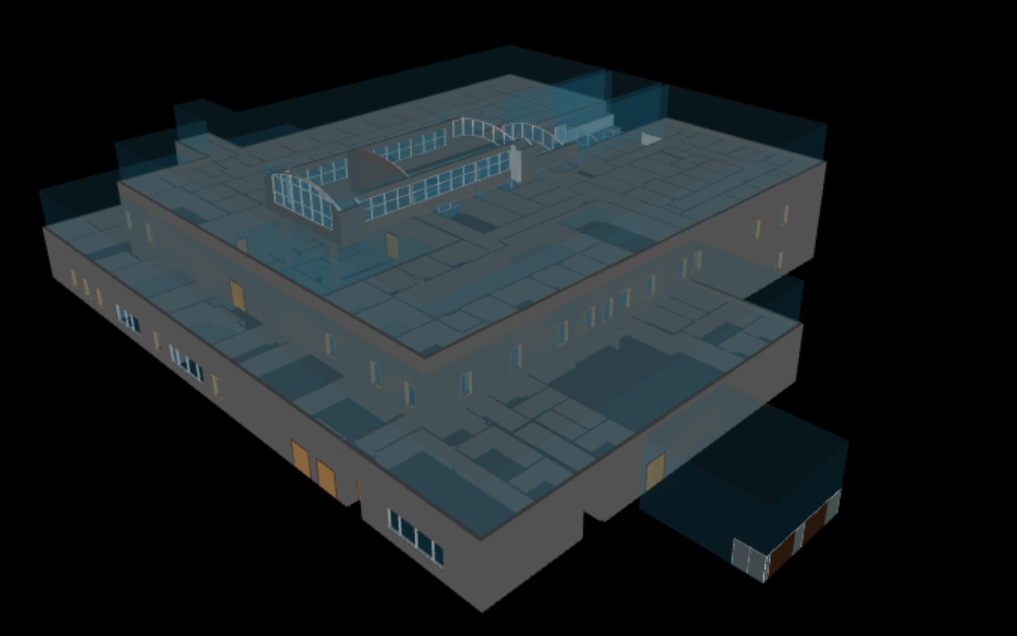


Figure 2 Clinic ifc file view

Additionally, "ifcbridge-model01.ifc" focuses on bridge structures, emphasizing civil engineering intricacies, while "schependomlaan.ifc" tackles large-scale urban planning model. The versatility of the conversion process is further examined through "tested\_sample\_project.ifc," a varied model combining architectural, structural, and infrastructural components within a single project.

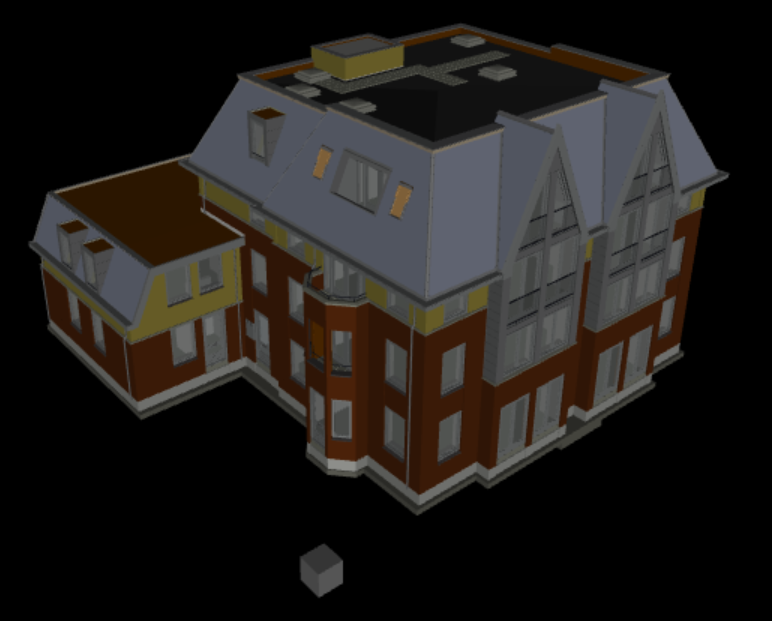


Figure 3 Residential house ifc file view

These test cases collectively provide a robust foundation for assessing the performance, accuracy, and efficiency of the proposed conversion mechanisms across a spectrum of realistic scenarios.

## TESTBED SPECIFICATION

The testbed for conducting experiments on the proposed conversion mechanisms is meticulously designed, considering both hardware and software components to ensure a reliable and consistent evaluation.

### HARDWARE REQUIREMENTS

To facilitate the experiments, the following hardware components have been specified:

* **Processor:** A multi-core processor with sufficient processing power to handle the computational demands of the conversion process.
* **Memory (RAM):** A substantial amount of RAM to accommodate the loading and processing of large-scale 3D models, minimizing the risk of memory-related bottlenecks.
* **Graphics Processing Unit (GPU):** A capable GPU to enhance the rendering and visualization aspects of the conversion, particularly when dealing with intricate geometric details.
* **Storage:** Adequate storage space to store the test cases, intermediate files, and the converted GIS-compatible models.

Considerations for system performance and resource utilization are paramount. The hardware configuration aims to strike a balance between computational power and memory resources, ensuring that experiments can be conducted efficiently without undue constraints on the testbed's capabilities.

### SOFTWARE INFRASTRUCTURE

The software infrastructure encompasses the operating environment and dependencies required to execute the conversion process effectively. The testbed operates within the following parameters:

* **Operating System:** The testbed is configured with a compatible operating system, ensuring seamless integration with the chosen conversion tools.
* **Dependencies:** Necessary dependencies, libraries, and frameworks are installed to support the functionalities of the web-ifc library, Three.js, and other associated utilities.
* **Configuration of Conversion Tools:** The specific configurations of the web-ifc library, Three.js, and the glTF-Pipeline utility are outlined, encompassing settings related to file parsing, geometric transformation, and compression.

# CONVERSION OF BIM MODELS TO GIS COMPATIBLE FORMATS

## SETTING UP CESIUM AS A GIS PLATFORM

Selecting a reliable GIS platform is essential when converting BIM models to formats that are compatible with geographic information systems. For this integration, CesiumJS, a JavaScript library for 3D globes and maps, proves to be an effective tool.

### INTRODUCTION TO CESIUMJS

An open-source JavaScript tool called CesiumJS makes it easier to create dynamic 3D maps in a web browser. Its high-performance rendering is facilitated by WebGL, and a multitude of geographical data types are supported. The library is well known for its adaptability in managing a wide range of geospatial applications, from showcasing intricate 3D models to visualising terrain.

#### OVERVIEW OF CESIUMJS FEATURES

CesiumJS is a top option for GIS applications due to its extensive feature set:

* High-quality rendering: Realistic representations of geographic data are made possible by CesiumJS's beautiful visualisations and high-quality rendering.
* landscape and images: For an immersive geospatial experience, the library offers detailed global landscape and images that smoothly interacts with Cesium World Terrain.
* Extensibility: CesiumJS is very expandable due to its modular nature. It is simple for users to add new features and alter the platform to meet the needs of certain projects.

#### CESIUM WORLD TERRAIN INTEGRATION

Cesium World Terrain integration is a key component of CesiumJS's capabilities. With this feature, the Earth's surface is accurately and at high resolution, adding to the authenticity of geographic visualisations. Through a smooth integration with Cesium World Terrain, the GIS platform can now represent many types of terrain, such as valleys, mountains, and other geographical characteristics.

Linking the required stylesheets and scripts inside the HTML text is the setup step for setting CesiumJS to utilise Cesium World Terrain. The integration prepares the groundwork for processing BIM models and converting them into forms that are compatible with GIS.

### CONFIGURING CESIUM ION

Setting up Cesium Ion becomes essential for optimising CesiumJS integration as a GIS platform. The processes for configuring Cesium Ion are explained in this section, with an emphasis on access token configuration.

Cesium Ion is a cloud-based technology that makes 3D geographic data easier to host and broadcast. The first step in using it is acquiring and setting up a Cesium Ion access token. By serving as a key, the access token provides the required authorization to communicate with Cesium Ion services. In order to obtain a special access token linked to their account, users must first register on the Cesium website. The access token has to be included into the CesiumJS application when it has been acquired. This ensures seamless communication between the application and the Cesium Ion platform, enabling the retrieval and display of hosted assets.

## HANDLING THE IFC FILE FORMAT FOR INTEGRATION

A crucial step in the conversion procedure is managing the IFC file format effectively. This section offers a thorough analysis of IFC, clarifying the features that affect its integration into the GIS context and providing insights into its function as a Building Information Modelling standard.

### UNDERSTANDING IFC

#### OVERVIEW OF IFC AS A BIM STANDARD

IFC is a neutral and open data format for the interchange of building and construction-related data. Acknowledged as a Building Information Modelling standard, IFC is essential for promoting compatibility across different software programmes utilised in the AEC (Architecture, Engineering, and Construction) sector.

IFC files offer a standardised representation of the built environment by encapsulating geometric and semantic data pertaining to building components. Adoption of IFC encourages data sharing and cooperation between many stakeholders throughout a construction project's lifespan.

#### CHARACTERISTICS OF IFC FILES

Understanding the characteristics inherent to IFC files is crucial for their seamless integration into the GIS environment:

* **Geometric Information:** IFC files contain detailed geometric information about building elements, including spatial coordinates, shapes, and relationships.
* **Semantic Representation:** Beyond geometry, IFC files incorporate semantic data, offering insights into the functional and conceptual aspects of building components.
* **Interoperability:** IFC promotes interoperability by providing a standardized format that transcends proprietary barriers. This enables the exchange of BIM data between different software applications.
* **Extensibility:** The extensible nature of IFC allows for the inclusion of additional information as needed, accommodating the evolving requirements of BIM applications.

### WEB-IFC LIBRARY INTEGRATION

An essential step in efficiently managing IFC files is including the Web-IFC library into the conversion procedure. This section explores how to handle IFC files using the Web-IFC library, including the procedures for importing and processing these files.

#### UTILIZING THE WEB-IFC LIBRARY FOR IFC FILE HANDLING

A JavaScript implementation of the IFC standard created especially for web applications is provided by the Web-IFC package. Making use of this library's resources is essential for processing and understanding IFC files in the context of the conversion process.

To enable smooth communication with IFC files, the Web-IFC library is included into the application's core. This phase makes sure that the IFC files' contained geometric and semantic data may be retrieved and modified for additional processing.

#### LOADING AND PROCESSING IFC FILES

Loading and processing IFC files using the Web-IFC library is a multi-step process that involves:

* **File Loading:** The Web-IFC library provides functions to load IFC files, either from local storage or remote sources. This involves reading the IFC file as a string, initiating the Web-IFC library, and opening the model for subsequent processing.
* **Mesh Extraction:** The library facilitates the extraction of geometric information from the IFC file, including the definition of building elements and their spatial coordinates.
* **Data Processing:** The loaded IFC data undergoes processing to transform it into a format compatible with web-based visualization. This may involve creating Three.js scenes or other data structures that can be easily integrated into the GIS platform.

## INTEGRATING IFC BUILDING MODELS INTO CESIUM

Integrating IFC building models into the Cesium platform, which enables the viewing of 3D assets in a geographical context, is an essential step in the conversion process.

### ENTITY CREATION FOR IFC MODELS

#### DEFINING CESIUM ENTITIES FOR MODEL REPRESENTATION

Since Cesium entities are the core building blocks for expressing and visualising geographic data, they play a crucial role in the CesiumJS framework. Cesium entities offer a potent technique for encapsulating each model in the context of integrating IFC building models, facilitating smooth manipulation and interaction inside the GIS platform.

An essential step in incorporating IFC building models into the Cesium environment is entity initialization. Every IFC building model is linked to a Cesium entity, and certain parameters are set upon setup. These parameters, which allow for effective monitoring and control of individual entities inside the CesiumJS framework, generally consist of the entity's name and a unique identifier.

The Cesium entity's Model URI (Uniform Resource Identifier) assignment is one of the main elements of this integration. The URI acts as a connection between the entity and the associated 3D model file, which is usually in the binary glTF or glTF (Graphics Library Transmission Format) formats. Through this partnership, the 3D model may be dynamically loaded and rendered inside the Cesium environment, improving the GIS platform's visualisation capabilities.

#### GEOGRAPHIC COORDINATES MAPPING

An important part of the integration process is mapping the geographic coordinates of IFC building models onto the Cesium globe. Since the Cesium environment uses a Cartesian coordinate system, the conversion process entails converting the geographic coordinates from the IFC model into the appropriate Cartesian coordinates. The virtual globe's architectural models are accurately represented and positioned thanks to this procedure.

An essential component of this conversion procedure is coordinate transformation. Strong geographic-to-Cartesian conversion methods are offered by Cesium, which convert latitude and longitude information from the IFC file into Cartesian coordinates appropriate for the Cesium environment. This conversion paves the way for precise geographical visualisation by enabling the smooth incorporation of geographic data into the three-dimensional realm that Cesium represents.

For accurate position in the three-dimensional space supplied by Cesium, elevation or altitude data associated with the IFC models must be taken into consideration in addition to latitude and longitude. The purpose of altitude adjustments is to take elevation differences into account and guarantee that the building models are positioned precisely at the designated heights above or below the reference surface. This stage, which takes into account both the vertical and horizontal dimensions, improves the overall correctness of the spatial representation.

The calculated Cartesian coordinates are where the Cesium object representing the IFC building model is placed once the geographic coordinates have been converted and altitude adjustments made. This guarantees that the object's position on the Cesium globe corresponds to its actual geographic location. In order to see and interact with the building models in the Cesium environment and give users a precise representation of the spatial data, the entity placement stage is essential.

### ASSET STRUCTURE AND LOADING

In addition to developing entities for model representation, maintaining the asset structure and loading procedure are also part of the process of integrating IFC building models into Cesium. This section describes the iterative loading technique of the Cesium Viewer and explores how assets, such as GLTF, GLB, and Draco GLTF types, are organised.

#### ORGANIZING ASSETS: GLTF, GLB, AND DRACO GLTF

A crucial component of the Cesium environment integration process is effective asset organisation, particularly when working with IFC building models that are transformed into formats like GLTF, GLB, or Draco GLTF. To achieve efficient loading and rendering and maximise performance on the three-dimensional GIS platform, these assets must be arranged properly.

Creating a well-organized folder hierarchy is a crucial step in asset organisation. All asset types—GLTF, GLB, and Draco GLTF files, among others—are arranged in specific directories. During the loading process, asset management and retrieval are made easier with this organised method. Developers can discover and load necessary files more quickly by organising assets according to their formats, which helps to create a more systematic and ordered integration.

When it comes to asset organisation, uniform naming practises are essential. It is ensured that assets may be easily identified and understood by using consistent and unambiguous naming conventions. To preserve a logical relationship between the converted assets and their original IFC models, asset names frequently correspond with the original IFC file names. This procedure improves the general asset organisation in the Cesium environment in addition to facilitating prompt identification.

When Draco compression is used on GLTF files, a unique method is used to emphasise this compression when asset organising. Draco-compressed GLTF files are usually separated into a different folder or label. Because of this particular organisation, handling and distinction during loading can be done in an effective manner, guaranteeing that the Cesium environment can manage and render Draco-compressed materials correctly.

#### ITERATIVE LOADING OF ASSETS INTO THE CESIUM VIEWER

The loading process within the Cesium Viewer is designed to be iterative, allowing for the dynamic incorporation of assets as needed.

To begin with, Asset Retrieval is the process of repeatedly obtaining assets from a structured folder structure based on user interactions, proximity to another location, or other dynamic parameters. By doing this, resource utilisation is optimised and pertinent assets are retrieved in response to user demands. Second, the Cesium Viewer uses dynamic loading to load GLTF, GLB, or Draco GLTF files whenever an object is required, starting the rendering process on demand. By minimising needless resource use and only loading assets when essential, this strategy improves efficiency. Lastly, the usage of Progressive Rendering enhances the user experience by enabling the progressive rendering of assets.

### VIEWER INTERACTION

The successful integration of IFC building models into Cesium extends beyond static representation; it involves enabling dynamic user interaction within the Cesium Viewer. This section explores the mechanisms for user engagement, allowing users to interact with the models and facilitating seamless navigation.

#### ENABLING USER INTERACTION WITH CESIUM VIEWER

User interaction is a critical component of GIS applications, and in the Cesium environment, powerful tools are used to enable smooth user interaction.

With its extensive navigation features, the Cesium Viewer allows users to tilt, zoom, and pan about in the geographical world. These controls offer a dynamic and interactive experience by enabling users to easily explore the integrated IFC building models. Users must be able to travel across the virtual world in order to examine and analyse the finer points of the geographical data that the IFC building models represent.

The Cesium Viewer's user interface is easy to use and straightforward, with navigation controls included. Users that are familiar with GIS systems will find the interface to be intuitive and comfortable. This guarantees that users can effectively traverse and interact with the integrated IFC building models. It also contains simple controls for adjusting the view and engaging with the models that are presented.

Carefully managing events is essential to allowing user interaction in the Cesium Viewer. Mouse clicks and gestures are examples of interaction events that are precisely controlled to initiate particular activities. This guarantees an environment that is responsive and easy to use, enabling users to meaningfully engage with the IFC building models. For example, clicking on a particular building object may cause further information to appear or start an action associated with that entity.

## PERFORMANCE METRICS AND MEASUREMENTS

The evaluation of the integration of IFC building models into Cesium extends beyond the visual representation and user interaction aspects. This section delves into the comprehensive assessment of performance metrics and measurements to gauge the efficiency and responsiveness of the entire conversion process.

### DEFINING PERFORMANCE METRICS

In order to systematically assess the performance of the conversion and integration processes, a set of key performance metrics are defined. These metrics are instrumental in quantifying various aspects of the system's behavior and efficiency.

#### METRICS FOR CONVERSION TIME

When assessing the effectiveness of the procedure that converts IFC files into formats that are compatible with GIS, conversion time is a crucial parameter. This measure takes into account a number of conversion process components, illuminating distinct phases and offering perceptions into the overall effectiveness.

An all-inclusive measure of the length of the complete conversion procedure is the total conversion time. It begins with the first IFC file loaded into the conversion programme and continues through the creation of formats suitable with GIS. This statistic gives stakeholders a comprehensive understanding of the conversion process' effectiveness and enables them to estimate the amount of time needed to fully convert IFC data into a format that can be used with GIS applications.

A granular metric called "individual file conversion time" calculates the time needed to convert each IFC file independently. This breakdown provides insightful information on the variation in conversion times among models. Comprehending the individual file conversion timings can be essential in locating possible bottlenecks, streamlining the conversion process, and resolving particular issues related to particular kinds or levels of complexity in IFC models.

Isolating the time required for this particular phase in the Draco compression process gives a targeted statistic to evaluate how the compression affects the whole conversion time. In order to optimise storage and loading speeds in GIS applications, draco compression is frequently used to minimise the size of GLTF files. It is possible to assess the trade-off between file size reduction and the extra processing time needed for compression by keeping an eye on the Draco compression time.

#### METRICS FOR MODEL LOADING TIME

*Model loading time pertains to the duration taken to load and display the 3D models within the Cesium Viewer.*

Three key performance indicators must be closely examined in order to fully assess the Cesium Viewer's effectiveness. First of all, the Total Model Loading Time is the total amount of time needed to load all integrated models into the Cesium Viewer's geographical context. This measure offers a comprehensive viewpoint on how effective it is to load numerous models at once. Second, by measuring the time required to load each model separately, the Individual Model Loading Time breaks down the loading procedure and provides more detail. This dissection enables a more sophisticated comprehension of possible variances in loading times depending on the intricacy of specific models. Last but not least, the Fly-To Time metric calculates how long it takes to complete the fly-to operation, providing insight into how smoothly switching between various model entities operates.

### MEASURING FILE SIZES

In addition to assessing the temporal aspects of the conversion and loading processes, evaluating the resulting file sizes is crucial for understanding the storage and bandwidth implications of the integrated assets.

#### CALCULATING AND ANALYZING GLB FILE SIZES

*The GLB file format, a binary representation of the glTF format, is a primary focus for file size analysis.*

* **Individual GLB File Size:** This metric quantifies the size of each GLB file after the conversion process. It provides insights into the storage requirements for individual models.
* **Cumulative GLB Size:** The sum of all GLB file sizes integrated into the Cesium Viewer. This metric offers a comprehensive view of the total storage footprint of the converted assets.
* **Compression Ratio:** The ratio of the original GLTF file size to the compressed GLB file size. This metric helps evaluate the effectiveness of the glTF to GLB conversion process.

#### ASSESSING DRACO COMPRESSED GLTF FILE SIZES

*For IFC files undergoing Draco compression, the resulting GLTF file sizes are of particular interest.*

Three important parameters are involved in the assessment of Draco compression inside the Cesium Viewer framework. First, the size of each GLTF file following Draco compression is measured by the Individual Draco Compressed GLTF File Size, which provides information about how compression affects certain models. Second, the Cumulative Draco Compressed GLTF Size gives an overall evaluation of the storage efficiency attained by compression by indicating the total amount of storage needed for all Draco-compressed assets in the Cesium Viewer. Finally, the Draco Compression Ratio is a numerical indicator of how well Draco compresses GLTF files, similar to the GLB compression ratio.

### VIEWER RESPONSIVENESS

The responsiveness of the Cesium Viewer is a critical aspect of user experience, directly influencing the usability and effectiveness of the integrated 3D building models. This section delves into the evaluation of viewer responsiveness and outlines strategies for addressing potential performance challenges.

#### EVALUATING USER EXPERIENCE AND RESPONSIVENESS

A thorough examination of important indicators is part of the Cesium Viewer's performance evaluation process. The frame rate is the most important factor to consider because it is directly related to how responsive the platform is. This analysis takes into account a range of circumstances, including differences in model complexity and the display of many models at the same time. Interaction latency is another important factor that highlights the lag between user actions such as rotating, panning, and zooming and the Cesium Viewer's response. This measure is essential for assessing the GIS platform's usefulness in real time. Furthermore, the seamlessness of views and model transitions is assessed, acknowledging that abrupt changes can greatly affect the user experience in general.

#### ADDRESSING VIEWER PERFORMANCE CHALLENGES

The key to improving the Cesium Viewer's speed is effective optimisation, which includes a variety of methods. Notably, techniques like occlusion culling, level-of-detail (LOD) modifications, and other optimisations are used to maintain a steady frame rate and guarantee a smooth user experience. By dynamically loading models depending on user proximity or relevance to the current view, dynamic loading techniques are essential in maximising resource utilisation and minimising the display of distant or occluded objects. Furthermore, real-time notifications during difficult rendering processes are provided by integrated feedback systems, which successfully manage expectations and promote a more transparent and user-friendly engagement with the GIS platform.

# RESULTS AND DISCUSSION

## PERFORMANCE METRICS AND MEASUREMENTS

The performance metrics and measurements provide crucial insights into the efficiency and effectiveness of the conversion and integration process. The following table summarizes key metrics for various IFC files:

Table 1 PERFORMANCE METRICS AND MEASUREMENTS

|  |  |  |  |
| --- | --- | --- | --- |
| FILE NAME | CONVERSION TIME (ms) | GEOMETRIES | FILE SIZE (MB) |
| clinic.ifc | 4599 | 4363 | 12.4 |
| advanced\_model.ifc | 21514 | 12053 | 33.67 |
| example.ifc | 1552 | 119 | 0.39 |
| ifcbridge-model01.ifc | 3173 | 2748 | 14.47 |
| schependomlaan.ifc | 8613 | 6037 | 47 |
| tested\_sample\_project.ifc | 2447 | 308 | 0.68 |

Conversion time is a dynamic measure that shows variation across distinct IFC files and illustrates the amount of time needed to complete the transformation. For example, converting "example.ifc" takes 1552 ms, whereas converting "advanced\_model.ifc" takes 21514 ms. It is essential to identify and examine these differences in order to maximise the integration workflow as a whole. Developers and GIS experts may identify possible bottlenecks, improve conversion algorithms, and increase the effectiveness of the transformation process by knowing the precise time investments for various IFC files.

The quantity of geometries handled throughout the conversion process offers important information about how complicated 3D models are and how it affects rendering performance after conversion. The file 'advanced\_model.ifc', for example, has more geometries than the other files, indicating a more complex structure. This intricacy affects the rendering performance in GIS apps later on as well as how long the conversion process takes. Through the assessment of the correlation between geometries and conversion time, developers are able to customise optimisation tactics to effectively tackle the unique obstacles presented by intricate models.

Another important consideration that should not be overlooked is file size, especially when it comes to web-based apps. For instance, "schependomlaan.ifc," with a file size of 47 MB, is notable. Due to its magnitude, considerable planning is required for effective asset hosting and streaming, particularly in situations where loading speeds and bandwidth are crucial. Developers must put procedures into place for file size optimisation and compression in order to maintain a balance between web-based GIS applications' performance and visual fidelity. In online contexts where huge file sizes may affect loading times and overall application performance, taking file size concerns into account becomes essential for delivering a responsive and smooth user experience.

## COMPARATIVE ANALYSIS

The comparative analysis of the performance metrics and measurements provides valuable insights into the nuances of the conversion and integration process. One key aspect of consideration is the relationship between conversion time and the number of geometries processed. This relationship is evident in the results, where the 'advanced\_model.ifc' file, exhibiting a higher geometric complexity with 12053 geometries, experiences a longer conversion time of 21514 milliseconds. On the other end of the spectrum, the 'example.ifc' file, with only 119 geometries, boasts a significantly shorter conversion time of 1552 milliseconds. This correlation suggests that the geometric intricacy of the 3D models plays a pivotal role in determining the time required for successful conversion.

Another crucial facet of the comparative analysis is the examination of file sizes resulting from the conversion process. File size is a pivotal factor in web-based applications, where efficient asset hosting and loading directly impact user experience. The 'schependomlaan.ifc' file, with a substantial file size of 47 megabytes, stands out as a noteworthy case. The larger file size necessitates careful considerations for optimal hosting strategies, efficient streaming, and potential trade-offs between visual fidelity and loading times. This observation underscores the importance of addressing file size implications to ensure a seamless and responsive user experience.

Moreover, the comparison study forces one to contemplate the integration approach's overall scalability. The performance features found in the current investigation become even more important as datasets are bigger and more complicated. To improve the system's scalability, optimisation paths including parallel processing and sophisticated compression must be investigated.

## DISCUSSION

### CONVERSION TIME AND GEOMETRIC COMPLEXITY

Analysing conversion timings for a variety of IFC files provides important new information on the connection between geometric complexity and conversion time. The file 'advanced\_model.ifc', which has a high geometric complexity of 12053 elements, is particularly notable for having a longer conversion time than files with fewer geometries. This discovery is in perfect accord with predictions, as the computational needs of handling complex geometric objects require greater time by nature.

The degree to which the geometric components in the 'advanced\_model.ifc' file are intricate determines how the conversion process behaves. The observed increase in conversion time can be attributed to the increased element count, which suggests a more complicated and comprehensive 3D model. Managing a large number of geometries comes with a computational cost that makes the conversion process labour- and resource-intensive. Consequently, the conversion time turns into an accurate representation of the intricate and sophisticated geometric structure of the IFC file.

Comprehending the relationship between conversion time and geometric complexity is crucial for optimising the integration procedure. This information may be used by developers to optimise algorithms, put parallel processing plans into practise, or investigate cutting-edge computational methods designed to speed up the translation of extremely complicated IFC models. Furthermore, this understanding lays the groundwork for creating adaptive solutions that dynamically modify processing techniques in response to the geometric complexity of certain files, making the conversion process more responsive and effective.

### FILE SIZE AND HOSTING CONSIDERATIONS

The file sizes resulting from the conversion process present a multifaceted consideration, with implications for both storage and user experience. The 'schependomlaan.ifc' file, with a notably large size of 47 megabytes, prompts discussions on effective hosting strategies, data streaming mechanisms, and potential trade-offs. Balancing the need for high-fidelity visual representations with the imperative of swift loading times becomes a focal point of consideration.

### SCALABILITY AND FUTURE DIRECTIONS

Scalability refers to the system's capacity to accommodate growing loads and bigger datasets without experiencing performance issues. Scalability concerns in the context of the IFC file integration that is being addressed entail examining the possible obstacles that may appear when working with a larger number of files, each of which can contain complex geometric structures. It is important to assess the scalability of the conversion and rendering performance in order to make sure that the integrated GIS application can adapt to the changing needs of spatial data representation.

Moreover, the conversation also includes a prospective examination that considers new developments in technology and developing industry standards for web-based GIS integration. Rapid technological advancements provide new tools, frameworks, and algorithms that might improve rendering capabilities and streamline conversion operations. Examining these developments and matching integration tactics with new best practises places the suggested method in a progressive framework that may change to meet the always changing GIS technology environment.

Scalability issues become crucial for the ongoing relevance and efficacy of integration techniques as GIS applications remain essential in tackling complex spatial difficulties. Developers may future-proof their systems and make sure that the integrated GIS application is responsive, dependable, and flexible to the ever-increasing needs of spatial data representation by proactively recognising and resolving scaling difficulties.

# CONCLUSION AND FUTURE WORK

In conclusion, this study has explored the complex terrain of incorporating 3D building models into the Cesium GIS platform, especially those in the IFC format. The investigation has shed light on the difficulties relating to performance concerns, conversion methods, and data formats. Creating a thorough conversion pipeline using CesiumJS and the Web-IFC library is a big step in the right direction to close the gap between these two different worlds. The results' performance metrics and measurements highlight the complicated interactions among model complexity, file sizes, and conversion times. The study has shown that a careful balance between fidelity and loading efficiency is necessary to achieve a seamless merging of 3D building models with GIS.

As for future work, there exist promising avenues for continued research and enhancement. The refinement of the conversion mechanism to address scalability challenges, optimization of loading strategies for even more extensive datasets, and the exploration of advanced compression techniques represent potential areas for improvement. Additionally, extending the integration framework to accommodate real-time updates and collaborative features could further augment its utility in dynamic urban planning scenarios. Moreover, the study opens the door for a broader examination of interoperability standards, exploring ways to facilitate the integration of diverse BIM formats beyond IFC. This expansion would contribute to a more inclusive GIS ecosystem capable of accommodating a diverse array of 3D models. In essence, this research lays the foundation for a more seamless coexistence between 3D building models and GIS, offering a holistic understanding of the built environment. The journey, as outlined in this dissertation, serves as a starting point for a continual evolution in spatial data integration, with the potential to reshape the landscape of urban planning, architecture, and decision-making processes.

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