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IMPROVED CADASTRAL DATA MANAGEMENT FOR FLOOD RISK MANAGEMENT IN A BIM-GIS COMPLIANT ENVIRONMENT BY ENGAGING STAKEHOLDERS

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Abstract

Flood risk management in the Netherlands is increasingly adopting decentralized, participatory approaches involving municipalities, property owners, and citizens. This research investigates the theoretical and practical aspects of integrating semantic 3D city models, Building Information Modeling (BIM), and Geographic Information Systems (GIS) within a unified framework to improve flood resilience. The proposed solution utilizes semantic web technologies to effectively link heterogeneous cadastral, building-level, and urban-scale datasets. Through stakeholder engagement, the study demonstrates enhanced data accuracy, interoperability, and informed decision-making capabilities, highlighting key theoretical advancements and insights gained from practical implementation and evaluation.

Introduction

The Netherlands is vulnerable to flooding. Due to this vulnerability, The Delta Programme, which is an example of the Dutch flood risk management strategy, is developed to tackle this challenge by preparing for multiple threads that the country will be facing with climate change (The Delta Programme, 2023). Historically large-scale flood defence systems, such as dikes and storm surge barriers, protect low areas in the Netherlands, which is referred to as 'fighting against water', with increasing concern that centralised strategies alone are insufficient. As a result, decentralised and participatory approaches are gaining momentum, and developers, citizens, and municipalities are playing a more active role in reducing flood risk and planning resilience.

The Netherlands developed the Multi-Level Safety (MLS) framework, which emphasises the role of local actors in enhancing flood resilience (Bosoni et al., 2023). It shifts responsibility from a top-down governance model to a collaborative approach that integrates government, private sector stakeholders, and citizens. One of the major challenges of this participatory approach is the collection, validation, and integration of heterogeneous data sources that describe flood resilience measures on the urban scale and on the building scale.

In parallel, digital technologies such as Building Information Modelling (BIM) and Geographic Information Systems (GIS) have gained prominence in urban resilience planning. Semantic 3D city models, particularly those based on CityGML and CityJSON, provide a structured, multi-scale representation of urban environments, supporting applications such as flood risk assessment, infrastructure monitoring, and land use planning. BIM, on the other hand, offers a detailed, object-oriented digital representation of individual buildings, capturing critical information related to construction materials, structural integrity, and flood defence mechanisms (FDMs). The combination of BIM and GIS presents an opportunity to develop more precise, data-driven approaches to flood risk management. However, the integration of BIM and GIS remains a major technical challenge due to differences in data formats, coordinate reference systems, and semantic structures.

This research investigates the integration of BIM, GIS, and participatory data collection within a web-based digital platform. The proposed system leverages semantic web technologies to enable cross-domain interoperability while preserving the geometric and semantic fidelity of spatial datasets. The platform is designed to allow property owners to submit flood resilience data at the building level, municipalities to review and approve these contributions, and government agencies to access a federated database containing cadastral, BIM, and flood management information. By implementing Resource Description Framework (RDF)-based data representation and SPARQL queries, the system facilitates seamless interaction between different data domains without requiring extensive data transformations.

This study aims to present findings on BIM-GIS integration, particularly in the context of participatory urban resilience planning. Additionally, it addresses practical challenges related to data governance, version control, and the large-scale visualization of urban flood defense mechanisms.

Literature Review

Flood Management in the Netherlands

The Netherlands, with two-thirds of its territory susceptible to flooding, has historically relied on large-scale flood defence structures such as dikes, storm surge barriers, and levees to protect its low-lying regions (Jongejan and Maaskant, 2015). The Delta Programme, a national strategy designed to prepare the country for climate change impacts such as rising sea levels, extreme weather events, and fluctuating river discharges, is central to flood risk management efforts. The programme operates under a long-term vision, aiming to make the Netherlands water-resilient by 2050 through a combination of infrastructure upgrades, land-use planning, and disaster preparedness.

The Multi-Level Safety (MLS) framework, introduced by the Foundation for Applied Water Research, is a key policy approach in Dutch flood management. This framework consists of three layers of protection: prevention, spatial planning, and disaster response. Prevention remains the primary focus, encompassing the maintenance and reinforcement of flood defences, such as dikes and storm surge barriers. Spatial planning involves urban design strategies aimed at reducing flood vulnerability, such as elevating buildings and restricting development in high-risk areas. Disaster response focusses on emergency preparedness and ensuring effective coordination between stakeholders during flood events.

Despite these measures, flood risk management has traditionally been a centralized effort led by the Dutch government, with limited public participation. However, as climate risks intensify, there has been a shift toward decentralized and participatory flood risk management, where municipalities and citizens play a more active role. This shift recognizes that citizen engagement can enhance flood resilience by improving local data accuracy and fostering greater public awareness. The transition from centralised control to collaborative governance underscores the importance of integrating geospatial technologies, cadastral data, and digital models to support evidence-based decision-making in flood management.

Within this evolving framework, decentralized measures at the property and neighborhood levels have gained increasing importance. In particular, individual property owners, municipalities, and developers are encouraged to implement FDMs as part of localized flood risk mitigation strategies.

FDMs refer to structural and non-structural measures installed at the building or parcel level to protect against flood impacts. These include permanent interventions such as flood barriers, raised thresholds, and watertight doors, as well as deployable systems like mobile flood gates. By empowering property owners to enhance their own flood resilience, FDMs complement large-scale infrastructural defenses and support the participatory objectives of modern flood risk management approaches.

Semantic 3D City Modelling and BIM

Semantic 3D city models are digital representations of urban environments that incorporate both geometric and semantic information (Kolbe and Donaubauer, 2021). Initially used for visualization purposes, these models have evolved with technological advancements, expanding their applications to various domains (Biljecki et al., 2015). The most widely adopted standards for semantic city modelling include CityGML and CityJSON, which define structured representations of buildings, terrain, and urban elements with rich attribute data. City models provide an essential foundation for flood risk analysis by enabling multi-scale simulations, visualisation of critical infrastructure, and integration with real-time sensor data.

Initially an enhanced 3D design tool, BIM has evolved to facilitate the efficient and effective data sharing across different stages and actors throughout the lifecycle of an AEC project (Doukari et al., 2023). It can be understood as a modeling technology and associated processes to produce, communicate, and analyze building models (Sacks et al., 2018). The Industry Foundation Classes (IFC), an open BIM standard developed by buildingSMART, provides a structured data model for describing architectural, structural, and infrastructural components. Unlike 3D city models, which primarily focus on city-wide representation, BIM models capture the detailed geometry, materials, and structural properties of individual buildings, making them crucial for assessing building-level flood resilience.

Alongside BIM and 3D city models, cadastral data plays a pivotal role in urban flood resilience. Cadastral records provide legal and administrative details about land parcels, including ownership, property boundaries, zoning regulations, and usage rights. Integrating cadastral data ensures that flood risk assessments are grounded in authoritative, up-to-date property information, linking urban-scale spatial models with building-level attributes and legal frameworks.

The increasing availability of open-source city datasets, such as the 3DBAG dataset in the Netherlands, has facilitated the adoption of 3D city models in urban planning. Similarly, advances in LiDAR technology and photogrammetry have improved the accuracy of digital representations, enabling more precise flood simulations and impact assessments. However, one of the main challenges in utilizing these models for flood risk management is the lack of interoperability between BIM and GIS datasets, which often operate in different coordinate systems, semantic schemas, and data structures.

BIM-GIS Integration

The integration of BIM and GIS has been widely recognised as a valuable strategy, with numerous researchers highlighting its applications across various stages of the AEC project lifecycles. Borrmann et al. (2021) provide a comprehensive overview of BIM-GIS integration use cases across different project stages, including planning (Marzouk and Othman, 2020), design (Niu et al., 2015), and operation (Chen et al., 2014).

Despite its potential, significant challenges remain in accurately capturing the micro-level representation of buildings within an urban context. Noardo et al. (2020) explain this challenge because of the fundamental differences between domains. BIM focuses on precise geometries and accurate measurements, whereas GIS prioritizes boundary representations with less emphasis on detailed geometries. For successful BIM-GIS integration, both geometry and semantics must be considered (Zhu et al., 2018). Geometric information includes the shape, location, and orientation of buildings and their components, while semantics encompass descriptive details such as attributes, relationships, and properties of building elements.

There are four key challenges in BIM-GIS integration (Deng et al., 2016). First, transforming the local placement system of IFC into the global coordinate system used by CityGML presents significant difficulties. Second, the geometric transformation process is technically complex, as IFC supports Swept Solids, CSG, and BRep, whereas CityGML is limited to BRep. Third, IFC does not provide direct mappings for all levels of detail (LOD) supported by CityGML, leading to data loss during conversion. Finally, this loss of data is further compounded by the different types of information stored in IFC and CityGML.

Four integration strategies have been proposed to bridge this gap (Liu et al., 2017). The conversion approach involves translating IFC models into CityGML, allowing data exchange between BIM and GIS systems. However, this method often results in loss of semantic information and reduced geometric accuracy. An alternative strategy is to extend existing information models, where additional semantic attributes are introduced to enhance interoperability. While this improves data alignment, it also increases model complexity and computational requirements.

Recent advancements have turned toward semantic web technologies, offering a more flexible and lossless integration approach. By representing BIM and GIS data as RDF triples and enabling dynamic querying through SPARQL, native semantic structures are preserved. This allows sophisticated cross-domain analyses, such as identifying buildings within flood-prone areas that lack validated flood defense mechanisms, without the need for data duplication.

Another emerging trend is the adoption of web-based 3D visualization tools, such as CesiumJS and IFC.js, which facilitate the real-time integration of BIM and GIS in browser-based platforms. These tools enable users to interactively explore multi-scale flood risk models, improving stakeholder engagement and decision-making processes. Despite these advancements, further research is needed to enable interoperability frameworks, and enhance version control mechanisms.

Nonetheless, significant challenges remain, particularly in establishing scalable interoperability frameworks, integrating comprehensive version control mechanisms, and ensuring governance across decentralized datasets. Fully leveraging BIM-GIS integration, enriched with cadastral data and participatory contributions, presents a major opportunity for advancing flood resilience and urban sustainability. Future flood management systems that combine semantic web technologies, federated data infrastructures, and multi-scale 3D visualization will be critical for supporting evidence-based planning and real-time decision support.

Research Methodology

Stakeholder requirements definition

The methodology was centred on understanding the needs of different stakeholders. The requirements were identified through a combination of semi-structured interviews, brainstorming sessions, and the results of the literature review. The interviews and brainstorming sessions involved experienced professionals from cadastral institutions, research and consultants working for municipalities. The main goal of this process was to understand the roles and responsibilities of these actors, along with the types of information and data models they typically handle and the potential added value of the system being developed. Moreover, the literature review provided context on the advances and challenges of flood risk management and BIM-GIS integration. This understanding led to the definition of the functional and non-functional requirements.

The functional requirements describe the specific functionality of the platform, focussing on the features of the system and the actions to be performed (Table 1). Non-functional requirements describe how the system should perform, focusing on the performance and usability, and defining the constraints and conditions that the system should meet (Table 2). In addition, all the requirements are classified following the must-have, should-have, could-have, and won't have (MoSCoW) prioritisation method (Clegg and Barker, 1994).

Table 1: Functional requirements

Group	Requirement	Classification
Account management	Account Creation	Should
	Login and Logout	Must
	Role-based access control	Must
City viewer features for property owners	Address search	Must
	Data upload	Must
IFC viewer features for property owners	IFC visualisation	Must
	FDM definition	Must
City viewer features for municipalities	FDM approval	Must
	Data querying	Must
Advanced visualisation	Visualise floor areas	Could
	Visualise buildings in city viewer	Could
	Visualise FDM	Could

After defining functional and nonfunctional requirements, two personas are created that represents potential users of this platform. The first persona is a property owner that does not have any technical knowledge but will use the platform to retrieve information regarding their property such as cadastral data and the IFC model. The second per-

Table 2: Nonfunctional requirements

Requirement	Classification
Open-source	Should
Web-based	Must
Federated database system	Must
Ease of use	Should
Scalability	Must
File modification	Should
Version Control	Could

sona represents an administrator that works for municipalities. They have the technical skill and necessary permissions to edit, query and upload data. From these personas and the requirements of the platform, it is possible to structure the use case diagram, depicted in Figure 1, highlighting the interactions between users and system, and providing a visual representation of the differences between them. As a result, the use case diagram serves as a reference for the development of the platform, while the requirements provided the foundation for its validation.

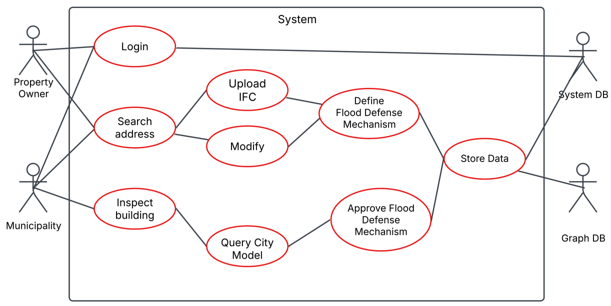

Figure 1: Use case diagram.

System Architecture

A modular system architecture (Figure 2) was designed to ensure flexibility and scalability. The backbone of this platform is created using Django, a python-based framework for the development of websites. Django follows the Model-View-Template architecture to organize its applications' logic into different layers. The model serves as the source of information about the data, containing the fields and behaviours that are being stored. By default, Django uses SQLite as its database and the model acts as an interface to this database. The view is responsible for processing user requests, interacting with the model, and returning the correct responses. They are represented by Python functions and determine what data should be sent to the template. Templates define the presentation layer and are commonly HTML files that describe how data should be presented in the browser. Moreover, Django provides a mechanism to map URLs to their corresponding views. When a user requests a URL, Django receives the URL, determines the appropriate view, which then checks for relevant data from the model, sends this data to a template, and the template generates the final HTML content to be returned to the browser. Django-based websites also follow a modular structure that allows for scalability. This is achieved by introducing applications, which are a combination of models, views, templates, and other components. Each application is a self-contained unit that performs a specific function within the project.

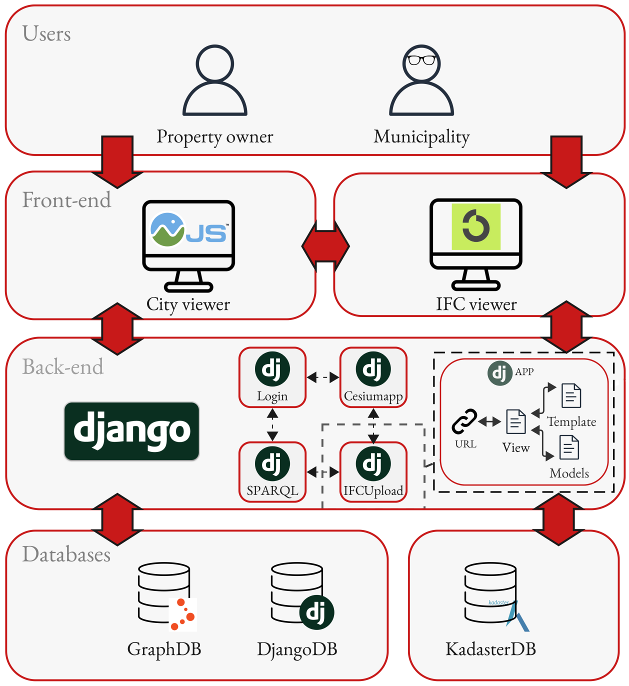

Figure 2: System architecture.

The system includes a 3D city viewer. For the development of the 3D city viewer Cesium which is an open platform that facilitates the development of 3D geospatial applications, is used. This is done by tiling heterogeneous data coming from multiple sources such as point clouds, imagery, and 3D city models. Additionally, each object represented in Cesium has a specified position and properties, which are used to define the interaction between applications and the visualization of the queries. Specifically, the 3D Basisvoorziening, a digital topographic dataset made publicly available by the PDOK is used in this project. It includes three-dimensional topographic representations of terrain, water bodies, roads, and buildings, derived from the BGT, BAG, and AHN. One of the novelties of this project lies in the use of OGC API-Tiles, a standard that outlines the essential components for creating Web APIs to facilitate the retrieval of geospatial information in a tiled format.

The use of 3D tiles brings significant benefits to the project. First, 3D tiles are optimized to stream large datasets, which allows the platform to handle a large amount of geospatial information efficiently. This is achieved by defining the rendering parameters, ensuring that users only visualize the data that is relevant to them. As a result, there is no need to impose geographical limits, and the platform can display any building or point of interest within the Netherlands. Secondly, streaming tiles avoids issues that could be associated with data transformations and mappings, which usually result in the loss of semantic and geometric information. Finally, the data come from an authoritative and legal source, the Dutch Kadaster. This ensures that the data uploaded by users can be validated against official records. Moreover, the data is updated yearly, bringing consistency and eliminating issues with data versioning.

The IFC viewer for this project is developed using the open source libraries from That Open Company, formerly known as IFC.js, which offer a modular architecture based on components to develop IFC viewers in a web browser. In addition to being able to define the FDMs of a property, users are able to generate clipping planes, view floor plans, take measurements, and view the attributes of the elements. The IFC viewer runs on a separate server from the Django app, although the two are closely connected.

The system employs multiple databases to store different types of data. Django's built-in database handles user authentication and session management, while a GraphDB instance stores RDF triples for semantic querying of BIM and GIS data. Additionally, the system retrieves cadastral data from Kadaster endpoints, ensuring access to authoritative records.

A federated SPARQL query mechanism facilitates interoperability across these datasets. By structuring data as linked semantic entities, the system enables cross-domain queries, such as identifying buildings in flood-prone zones that lack validated FDMs.

Implementation

The implementation of the platform was structured to ensure seamless integration of cadastral data, BIM models, and FDMs within a web-based environment. This process involved the development of multiple interdependent modules, including user authentication, data querying, file management, and visualization tools.

User authentication was implemented using Django's built-in authentication system, which allowed for role-based access control. Users were categorized into two personas that was discussed before. The authentication mechanism ensured that each user had appropriate permissions to interact with specific datasets.

The querying functionality was designed to enable users to retrieve cadastral data from the official Dutch Kadaster database. This was achieved through SPARQL queries, which facilitated the dynamic retrieval of information while preserving the semantic integrity of the datasets. Users could search for buildings using identifiers such as address or cadastral code, allowing efficient access to property information (Figure 3).

A core component of the platform was its ability to support the upload and visualization of IFC files, which contain detailed building models. The IFC viewer, implemented using open-source libraries, enabled users to inspect the geometric and semantic properties of their buildings. Additionally, the platform supported the definition and annotation of FDMs within the IFC models (Figure 4). These annotations allowed property owners to specify flood protection measures such as watertight doors, elevated foundations, or barriers.

Municipal officials played a crucial role in reviewing and approving user-submitted FDMs. The validation process ensured that only verified flood defence data was integrated into the system. Once an FDM was approved, it was converted into RDF triples and stored within a semantic graph database. This approach maintained interoperability between different data sources while enabling cross-domain queries.

To facilitate data visualisation, the platform incorporated CesiumJS for rendering 3D city models. This allowed users to interact with urban-scale representations while linking them to detailed building-level information. However, challenges were encountered in rendering high-resolution IFC models within the Cesium environment. Although property-level data could be visualised within the IFC viewer, incorporating these details into the city viewer required additional processing steps, such as generating 3D tiles from semantic attributes.

A significant advancement was the introduction of federated data integration, where cadastral, building, and flood defence datasets were linked using semantic web technologies. This enabled users to perform integrated searches, combining information from multiple sources without redundancy. Queries could be constructed to identify critical infrastructure, such as schools and hospitals, located within flood-prone areas.

In summary, the implementation phase successfully developed a modular, interoperable, and web-based platform that integrates BIM and GIS data for flood risk management. By leveraging semantic web technologies, open source visualisation tools and federated querying, the system provides a foundation for participatory flood resilience planning. However, enhancements in data visualization, version control, and geospatial accuracy remain areas for future improvement.

Results and Validation

The validation of the developed platform aimed to assess the extent to which the system met its functional and non-functional requirements, as well as to identify areas requiring further improvement. The results indicate that the platform successfully integrates cadastral data, BIM, and GIS within a federated semantic web framework. However, certain functional aspects, particularly in visualization and data versioning, remained partially unmet.

The integration of cadastral, building, and flood defence data was achieved through a federated query system that links authoritative sources, such as the Dutch Kadaster, with semantic representations of IFC data. The use of SPARQL queries enabled the retrieval of relevant data across these domains, allowing for a seamless querying process that linked building records with FDMs. Valida-

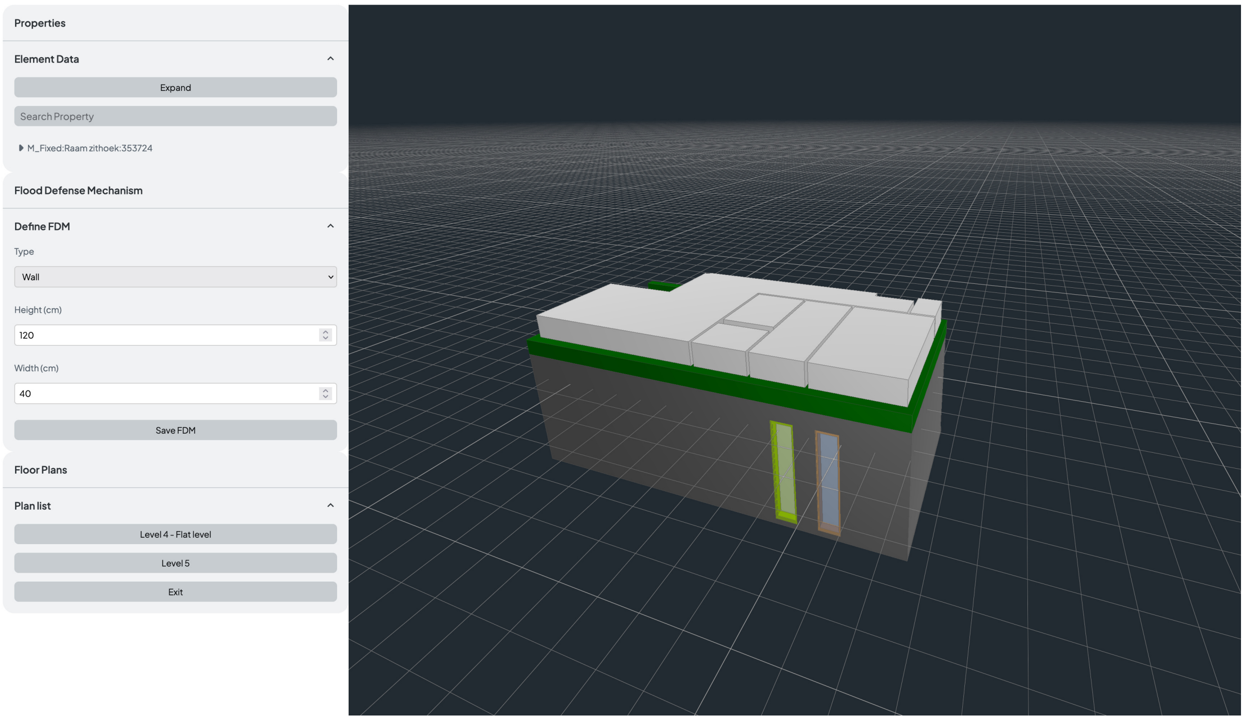

Figure 3: Defining FDM within the viewer.

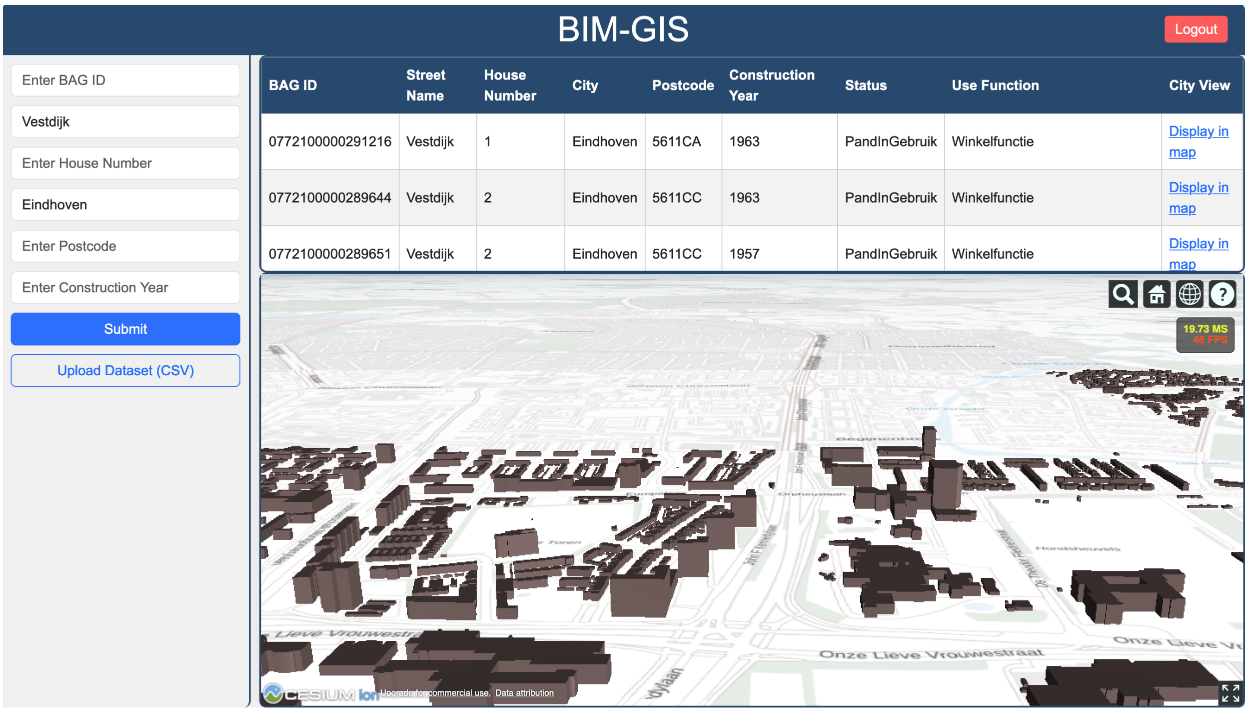

Figure 4: Address search functionality.

tion demonstrated that municipal authorities could effectively access and review property owner submitted flood defence annotations, ensuring data integrity and compliance with established flood resilience measures.

Despite the success of the data integration framework, the visualization of FDMs within the city viewer remained an outstanding challenge. The Cesium-based 3D viewer effectively displayed cadastral and BIM data, but the system lacked an intuitive method to represent FDMs. Addressing this issue would require generating 3D tiles from the semantic properties of FDMs, thereby enabling users to interact with flood defence elements in a more intuitive manner. Additionally, the correct georeferencing of these elements poses a challenge, particularly for FDMs that do not belong to individual buildings but exist at the urban level, such as flood barriers or water retention structures.

The authentication and role-based access control functionalities of the platform performed as expected, distinguishing between property owners, municipal officials, and public users. Property owners were able to submit FDM definitions for review, while municipal officials retained the authority to approve or reject these submissions. However, the lack of a two-way communication mechanism was identified as a limitation. Currently, municipalities can approve flood defence annotations, but cannot provide structured feedback or request modifications prior to final acceptance. Implementing a feedback loop would enhance the participatory aspect of the system and improve data reliability over time.

The handling of IFC file uploads and conversion to RDF format was another key area evaluated. The platform successfully processed IFC submissions, converting relevant elements into RDF triples and storing them in GraphDB. However, issues with syntax validation and RDF conversion were noted. Certain IFC attributes, particularly those containing abbreviations or special characters, resulted in invalid RDF representations, preventing their proper integration into the semantic database. Future iterations of the platform should include syntax validation mechanisms to ensure that IFC attributes conform to expected formats before conversion.

Another significant challenge was the lack of version control for IFC data. Given that flood resilience measures evolve over time, ensuring that the system maintains historical records of FDM modifications is essential. The current implementation lacks a structured versioning mechanism, meaning that updates to building models and flood defence elements overwrite previous records without maintaining a change history. Implementing version control for RDF data would allow for better tracking of modifications and improve the reliability of long-term flood resilience planning. Therefore, version control should be regarded as a functional requirement rather than nonfunctional requirement for future implementations.

During the evaluation phase, it became evident that scalability and performance optimization require further refinement. While the modular structure of the platform ensures that additional datasets can be incorporated, performance bottlenecks were encountered when visualizing high-resolution IFC models in the 3D environment. This issue was particularly pronounced when handling complex building geometries with multiple flood defence annotations. Adopting Level of Detail (LOD) techniques or alternative rendering optimizations would improve the platform's ability to handle large-scale urban datasets without compromising performance.

Overall, the validation process confirmed that the platform provides a viable approach for integrating BIM, GIS, and citizen-contributed flood risk data. The ability to query cadastral and BIM data within a federated system was successfully demonstrated, and the participatory nature of the platform showed potential for improving flood resilience planning. However, further refinements are necessary in visualisation, version control, and bidirectional communication mechanisms to fully realize the potential of the system for large-scale urban resilience applications.

Conclusions and Future Work

This research presents a semantic web-based platform designed to enhance participatory flood risk management by integrating heterogeneous cadastral, BIM, and GIS datasets. The platform applies RDF technologies and federated SPARQL queries to enable dynamic, cross-domain interoperability while preserving the semantic and geometric integrity of the data. Tested in a real-world context, the platform demonstrates how integrating authoritative cadastral information with semantic 3D city models and detailed building-level data can support more accurate and stakeholder-driven flood resilience planning.

Compared to traditional integration approaches, the use of semantic web technologies addresses several longstanding challenges in BIM-GIS interoperability, including data transformation losses, misalignment of coordinate systems, and semantic mismatches. By linking data instead of transforming it, the platform maintains the original richness of building and spatial information. Additionally, the direct inclusion of cadastral data enhances the administrative and legal validation of FDM submissions, supporting transparent decision-making by municipalities and property owners alike.

The platform further incorporates a version control mechanism to track changes to property resilience measures over time. Although full RDF-native versioning remains complex, the initial implementation of update tracking establishes an essential foundation for future auditing and regulatory compliance in decentralized flood management systems.

Despite these advances, certain limitations remain. Visualization of IFC models directly within the urban-scale city viewer remains constrained by technical challenges in rendering high-detail geometries at scale. Moreover, semantic version control across federated linked data endpoints introduces complexities that require further research. Addressing these challenges will be critical for scaling the platform to larger urban areas and integrating real-time flood simulation data.

In conclusion, this study contributes to both theory and practice by demonstrating the feasibility and value of semantic web technologies in bridging BIM, GIS, and cadastral domains for participatory flood risk management. Future work should focus on advancing semantic versioning methods, enhancing multi-source visualization capabilities, and expanding platform functionalities to incorporate predictive flood modeling and broader urban resilience applications.

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