

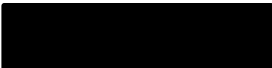
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Assessment and Mitigation of Flooding Scenarios for the LMU Hospital, Munich through BIM-GIS Integration

**Scientific work to obtain the degree of Master of Science (M.Sc.)
in Civil Engineering**

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Preface

As I embark on the journey of presenting this thesis, I am acutely aware of the vital importance of effective flood risk management in our increasingly unpredictable climate. The decision to focus on the LMU hospital campus in Munich's Zimmensblock area for this study was driven by the need to safeguard critical infrastructure and ensure public safety in the face of natural disasters.

In recent years, the spectre of climate change has loomed large, making extreme weather events like heavy rainfall recently, in some other states of Germany and subsequent flooding a more frequent reality.

This thesis is the culmination of extensive research, data analysis, and simulation work, the goal of which is to not only understand the flood risks but also to provide a blueprint for the development of robust flood management strategies. It reflects the interdisciplinary nature of contemporary research, lying at the intersection of environmental science, urban planning, and technological innovation.

The journey of crafting this thesis has been both challenging and enlightening. It has been a privilege to work with experts from various fields, to learn from historical data, and to employ advanced machine learning techniques. I am deeply grateful for the guidance of my academic mentors, the support of my peers, and the collaboration with the authorities of Munich and the LMU campus, all of whom have contributed significantly to this work.

I would also like to extend my special thanks to Miss Pavla Rýzlerová, Mr. August Pries from LBD, and Mr. Jonas Hürten from the Water Department. Your contributions, both in expertise and support, have been invaluable. Your willingness to share your knowledge and collaborate has greatly enhanced the quality and impact of this research. With this preface, I invite you to delve into the pages that follow, which detail the methodology, findings, and implications of this critical work in flood risk management.

Abstract

Flood simulation and documentation are fundamentals in the realm of flood management, offering indispensable tools for predicting, understanding, and effectively responding to potential flood events. By harnessing the capabilities of advanced technologies like Geographic Information Systems (GIS) and Building Information Modeling (BIM), flood simulation could allow us to envision and understand various flood scenarios due to heavy precipitation, which can result in informed decision-making and proactive measures.

Integrating precise terrain data, hydrological information, and building models, paved/non-paved surfaces, soil characteristics, storm water drainage, these simulations may offer comprehensive insights into flood extents, vulnerable areas, and potential infrastructure impacts. Concurrently, flood documentation also contributes a major role in recording historical flood events, their consequences on buildings and infrastructure and the efficacy of response strategies. This documentation lays the foundation for post-flood assessments, and continual improvements in flood management practices, bolstering community resilience and mitigating the devastating effects of flooding.

This thesis aims to employ BIM and GIS modelling to calculate and simulate these flood scenarios accurately to equip Munich's authorities with valuable insights to develop robust flood management strategies and safeguard vital assets and public building at the LMU hospital campus.

Summary

This thesis presents a comprehensive approach to flood risk management for the LMU hospital campus located in the Zimmensblock area of Munich. Employing advanced Geographic Information Systems (GIS) and Building Information Modeling (BIM), the study aims to simulate various flood scenarios precipitated by heavy rainfall and to understand their potential impacts. Such simulations are crucial for equipping Munich's authorities with the insights needed to develop effective flood management strategies and to protect vital assets and public buildings.

Contents

1	Introduction and Motivation	1
1.1	Aim of the Thesis.....	1
1.2	Area of Interest.....	2
1.3	Structure of Work	3
2	Literature Review	4
2.1	Towards an Integration of GIS and BIM data: What are the Geometric and the Topological Issues? (<i>Ohori et al., 2017</i>).....	4
2.1.1	Methodology.....	4
2.1.2	Results	6
2.2	An Integrated BIM–GIS Method for Planning of Water Distribution System (<i>Zhao,2019</i>).....	7
2.2.1	Methodology.....	7
2.2.2	Results	10
2.3	A Preliminary Contribution towards a Risk-Based Model for Flood Management Planning Using BIM: A Case Study of Lisbon (<i>Del Duca,2022</i>).....	10
3	Methodology	12
3.1	Data Collection	12
3.2	Data Preparation	19
3.3	Integration	27
3.3.1	Model Integration.....	27
3.3.2	Hydrological Data Integration	29
3.4	Visualization	47
3.4.1	Weather API integration	47
3.4.2	Web application.....	49
3.4.3	Setting Up Game Engine with Unreal Engines.....	58
3.4.4	Sewage Network	60
4	Result	67
4.1	Simulation Based on Historical Data	67

4.2	Simulation results from Statistical Data	68
4.2.1	Result from 10-year return period	68
4.2.2	Result from 100-year of return period	69
4.3	Simulation results from ML prediction model	70
4.4	Visualization from Unreal Engines	71
5	Conclusion	72
6	Discussion	74
7	Methods For Flood Mitigation	76
	References	77
8	List of Figures	80
9	List of Tables	82
10	Declaration	84

List of Abbreviations

BIM	Building Information Modelling
GIS	Geographic Information Systems
LMU	Ludwig-Maximilian-Universität München
IFC	Industry Foundation Class
OGC	Open Geospatial Consortium
LoD	Level of Detail
UTM	Universal Transverse Mercator

1 Introduction and Motivation

The integration of Flood Simulation using Building Information Modeling (BIM) and Geographic Information Systems (GIS) data heralds a novel advancement in flood mitigation strategies. BIM can provide us with intricate geometric and semantic information which offers a opportunity to enhance the accuracy of flood simulation and prediction. By harnessing the power of BIM and GIS in flood management, we could create a more refined and effective approach to deal with flooding events. The amount of detail provided in BIM, is well-known for its capacity to provide exact and thorough data about buildings and landscapes, greatly increases the accuracy of flood simulations. This includes not only the geometric properties of buildings and infrastructure but also the semantic information of the buildings which describes their functions and materials. Additionally, GIS data complements BIM by providing valuable geographic context. GIS integrates information about topography, hydrology, land use, and more, allowing to create a holistic view of the environment in which flooding occurs. The incorporation of this contextual information improves flood prediction models by taking into account the larger environment and its relationship to constructed structures.

In this thesis we delve into the intricate task of simulating various flood scenarios within the historical Ziemmensblock area at LMU Hospital, a significant location in Munich. Our approach involves the integration of multifaceted data sources, comprising terrain information, hydrological data, detailed building models, surface material distinctions (paved and non-paved), and soil attribute assessments to determine infiltration rates. Additionally, we consider the intricate network of stormwater drainage systems, all of which serve as crucial inputs to our comprehensive flood simulation model.

1.1 Aim of the Thesis

The primary aim of this thesis is to develop and present a methodological approach that leverages Building Information Modelling (BIM) and Geographic Information Systems (GIS) for simulating various flood scenarios in the LMU hospital area. This approach is intended to facilitate a comprehensive understanding of the potential impacts of flooding, enabling the identification of vulnerable locations and the assessment of

effects on critical public infrastructure. By integrating sophisticated modelling techniques with a diverse array of datasets, the thesis endeavours to provide a detailed overview of the potential extent of flooding, contribute insights for flood management strategies, and enhance preparedness measures. A significant focus is placed on ensuring the protection of this historically significant and crucial site within Munich, thereby contributing to the community's resilience against the catastrophic consequences of flooding. Furthermore, the documentation outlines a basis for post-flood evaluation and the continuous improvement of flood control measures. Ultimately, this methodological framework aims to supply Munich's authorities with actionable information to devise effective flood management plans and safeguard essential assets, thus underpinning a resilient and well-prepared community in the face of flood risks.

1.2 Area of Interest

The study focuses on flooding scenarios for the LMU-hospital located in the historical part of Munich, specifically in the urban district Ludwigsvorstadt/Isarvorstadt, within the area of so called “Ziemssenblock” bounded by Nussbaumstraße, Ziemssenstraße, Lindwurmstraße, and Goethestraße.



Figure 1 Innenstadt clinic LMU

1.3 Structure of Work

The thesis is organized into the following structured components:

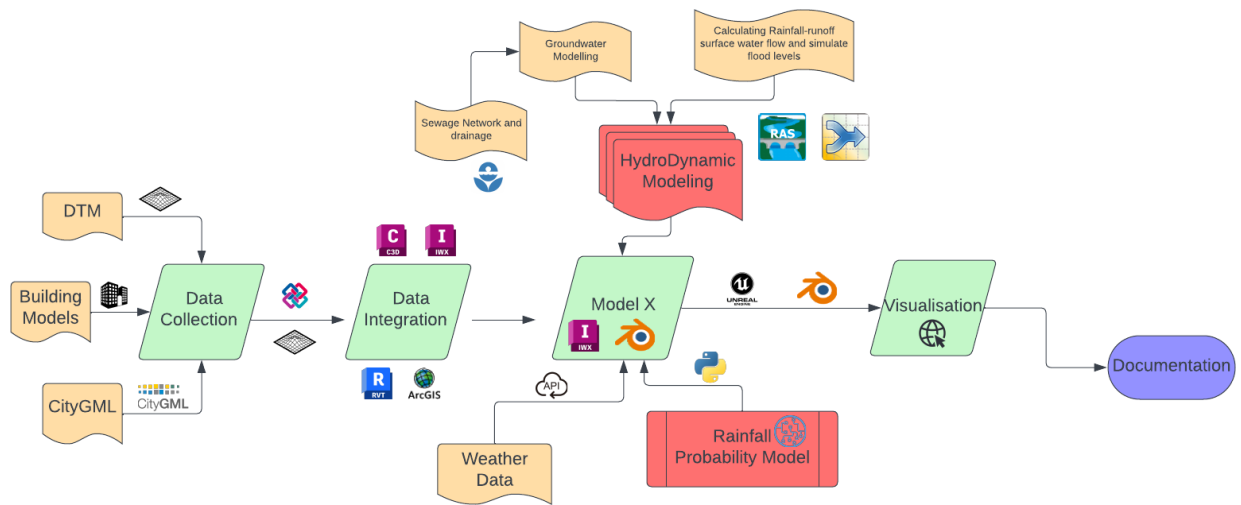


Figure 2 Overview of the developed method and workflow

- Data Collection and integration:** We initiate our research by collecting data from different public authorities in Munich. This data includes a digital terrain model of the city, IFC models of various clinics at the LMU hospital, soil characteristics, land use and the crucial step of georeferencing IFC models within the broader geographical context and integrating everything into a single model.
- Hydrological Modelling:** The next phase involves the development of a robust hydrological model. This encompasses the calculation of rainfall-runoff dynamics, an assessment of surface water flow patterns from historical precipitation data, and the estimation of water flow behaviours through statistical and machine learning approaches. This phase is pivotal in understanding the hydrological aspects of our study area.
- Visualization and Simulation:** The final segment of our work revolves around visualization and simulation. Here, we leverage the gathered data and the hydrological model to simulate various flooding scenarios within our area of interest. This step offers a practical and illustrative insight into potential flood outcomes.
- This structured approach allows us to methodically progress from data acquisition through hydrological analysis to the ultimate visualization and simulation of flood scenarios in our designated study area.

2 Literature Review

For the purpose of the thesis following literature review were made and detailed below:

2.1 Towards an Integration of GIS and BIM data: What are the Geometric and the Topological Issues? (*Ohori et al., 2017*)

The practical difficulties of combining Geographic Information Systems (GIS) and Building Information Modelling (BIM) at the data level—a synergy thought to be advantageous for both domains—are examined in this paper. While GIS offers a more comprehensive contextual perspective, BIM includes detailed information on buildings and infrastructure. Prior research has mostly focused on the theoretical elements of schema-level BIM-GIS integration. This paper's focus, however, is on the practical geometric and topological difficulties encountered in software development for this integration. The paper's initial findings highlight several unresolved issues: managing geometric and topological complexities in BIM models, addressing inaccuracies in georeferencing, and determining the most effective methods for data conversion between IFC (Industry Foundation Classes) and CityGML (City Geography Markup Language). These challenges underscore the need for further research and development in this area.

2.1.1 Methodology

The literature review initiates by detailing the method of parsing and processing each object within the IFC framework, employing a customized variant of `IfcOpenShell`. This is integrated with a substitution of the original kernel, which is based on `openCASCADE`, with a novel one that leverages the Computational Geometry Algorithms Library (CGAL). Through this approach, the paper harmonizes the geometrical data from GIS and BIM within a unified data environment. It also ensures alignment between the instances of CityGML and IFC, maintaining a consistent link between these datasets. The representations for different geometric forms include points, polygonal curves, and polygons with holes. Implicit and parametric curves, surfaces, and volumes from the IFC files are transformed into explicit boundary representations, which are then discretized into polygonal curves and meshes.

Additionally, all placements and transformations in IFC are translated into 3D affine transformations, defined by matrices, and applied recursively to each object. This results in a polyhedral representation of every volumetric object, stored as a CGAL Polyhedron 3.

Furthermore, certain IFC entity types such as CSG(Constructive solid geometry) solid, half-space, and Boolean result representations require extra processing steps. These involve converting a polyhedron into a CGAL Nef polyhedron 3, followed by performing Boolean set operations like union, intersection, or difference. Through these steps, the methodology effectively brings together the detailed architectural data of BIM and the expansive environmental context of GIS, allowing for intricate spatial analysis and geometric operations within a cohesive framework.

In their study, the authors discovered that invalid objects are a common issue in the IFC models they analyzed, aligning with previous experiences in BIM and GIS data. The most frequent errors include self-intersections and intersections between objects, surfaces that are uneven but meant to be planar, and disconnected objects modeled as one. A particularly notable error involved objects that appeared valid and formed topological 2-manifolds but actually contained self-intersections, a violation of the IFC standard.

The strategies to counter the challenges are provided below :

Triangulation for Planarity: They triangulated non-triangular faces of objects to ensure planarity, aiding the conversion from CGAL Polyhedron 3 to Nef polyhedron 3. This approach guarantees that a plane passes through every face.

Validation Tests: A series of validation tests were performed on every object and its openings. These tests, conducted at various stages of the object's construction, checked for enclosed spaces, issues with CGAL's triangulation algorithm, self-intersections, and failures during conversion to Nef polyhedron 3.

Discretization of Implicit Geometries: The implicit and curved geometries in IFC were discretized into explicit b-rep linear geometries. Methods varied, like discretizing ellipses into polygonal curves using equal-angle intervals and spheres into icosahedral approximations.

Challenges with CGAL Features: The authors noted that CGAL's features were insufficient for modeling all complex features of IFC. They encountered compatibility issues with CGAL Nef polyhedra and the extended kernel needed for half-space representations. Challenges also arose in constructing meshes that don't enclose a volume or creating a Polyhedron 3 from a mesh in a Nef polyhedron.

Another challenge was regarding bad georeferencing of IFC models, the IFC standard includes entities and attributes specifically for georeferencing models, allowing for the precise location of a model on a geographic coordinate system by combining latitude, longitude, elevation attributes of the IfcSite, and the model's true North orientation. However, the paper found that these georeferencing attributes are often incorrectly filled by practitioners. This discrepancy is exemplified by a case where the provided coordinates for a model in The Hague were significantly inaccurate, placing the model at the center of a roundabout instead of its actual location.

Such inaccuracies can be substantial, with examples ranging from a few kilometers to incorrect placements in entirely different cities or continents. These errors are attributed to the lack of emphasis on georeferencing during the design phase by BIM practitioners and the lack of strict rules or specifications mandating accurate georeferencing information in IFC file generation.

2.1.2 Results

Geometrical and Topological Errors: BIM models often contain numerous geometric and topological errors, which, while not problematic in a BIM context, pose significant challenges for GIS applications that require precise spatial analyses and operations.

Limited Scope of Transformation: Because of the complexity and large number of IFC entities, the project has only created conversions for a portion of the IFC standard thus far. It appears more practical to concentrate on the most often used and readily convertible entities to polyhedral representations rather than trying to cover every entity.

Need for Standardisation: There is a pressing need for standardisation in the transformation process from IFC to CityGML. Different interpretations and approaches to this transformation can lead to varied outcomes, underscoring the need for a uniform and standardised method, particularly for creating sustainable information chains.

Detail Level in Integration: Given the higher detail in BIM data compared to GIS, a fully detailed integration is unlikely. Instead, a generalised version of BIM models with relevant GIS attributes is more practical.

The project's future direction of the paper involves formulating recommendations for BIM practitioners and standardisation bodies to enhance integration possibilities, identifying key semantics to be preserved in the transformation process, and further developing the IFC/CityGML interface. These efforts will be grounded in practical use cases to ensure alignment with real-world needs. This approach signifies a significant step towards effective integration of BIM and GIS data, addressing both technical challenges and the need for standardisation and compatibility.

2.2 An Integrated BIM–GIS Method for Planning of Water Distribution System (Zhao, 2019)

The paper proposes an innovative method integrating Building Information Modelling (BIM) and Geographic Information Systems (GIS) for planning water distribution systems (WDS). The integration aims to enhance planning efficiency, reduce conflicts during construction, and improve sustainable development in urban areas.

2.2.1 Methodology

Integration of BIM and GIS Using Semantic Mapping

Industry Foundation Classes (IFC) and City Geography Markup Language (CityGML): These are the chosen data schemas for BIM and GIS respectively, due to their neutrality and wide acceptance. The integration process employs semantic mapping to harmonize these models, ensuring efficient data transformation and sharing.

Mapping IFC Data into CityGML System: This involves correlating IFC's comprehensive structure for pipe networks with CityGML's model. The IFC schema details the relationships among pipe networks, segments, and connections, while CityGML represents the basic structure of various types of networks in a GIS environment. The mapping process ensures that the intricate details of the pipe network in the BIM environment are accurately represented in the GIS model.

3D Visualization Model:

Surface Model Development: Utilizes a Triangulated Irregular Network (TIN) surface model in GIS to represent the site topography, providing a vivid 3D view of different terrains like valleys and ridges. The topographic survey data, including coordinates and elevations, are first imported into AutoCAD, and then transferred to ArcGIS to form a geodatabase.

Modelling of Existing Buildings: Involves identifying building locations and footprints from aerial images, assigning elevation values from the surface model, and developing a 3D model in SketchUp. This model is then integrated back into GIS.

Modelling of Pipe Network Systems: Focuses on creating a 3D model of existing and proposed pipe systems. CAD drawings of pipe systems are imported into Revit for 3D modelling, which are followed by storing the information in IFC schema and incorporating it into ArcGIS using CityGML/Utility Network.

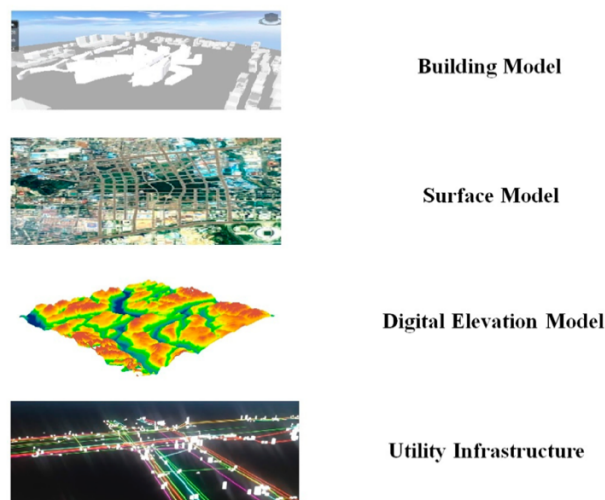


Figure 3 Different Layers in the model

Topological Validation Process

Identifying and Setting Topological Rules: A crucial step to examine spatial conflicts between the proposed WDS project and existing structures. The topology tool in GIS, with a set of validation rules for points, lines, and areas (PLAs), is used to ensure the spatial consistency of the network and prevent redundancy.

Process of Topological Analysis and Error Identification: Involves setting PLAs and topological rules, determining cluster tolerance, and assigning topological rules that govern spatial relationships. The topology validation process then identifies any violations or conflicts, which are marked and reported for corrections.

Topology Editing and Revalidation: Utilizes ArcGIS's topology editing tools to fix identified errors. The changes are saved in topology, and the topological rules are revalidated to ensure compliance.

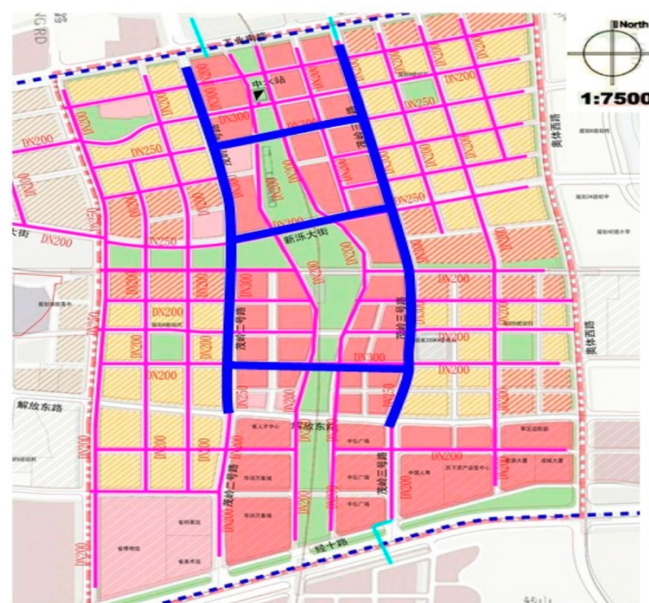


Figure 4 Water distribution in ArcGIS

This comprehensive methodology demonstrates a detailed integration of BIM and GIS for efficient and conflict-free planning of water distribution systems, showcasing an innovative approach to urban planning and infrastructure development.

2.2.2 Results

The application of this integrated method was tested on a real WDS project in Jinan, Shandong Province, China enhanced understanding of the WDS project and its interaction with the surroundings. The key benefits also include:

- Improved decision-making, considering on-site physical constraints and avoiding unrealistic layouts.
- The development of a reliable WDS plan without conflicts, ensuring efficient use of space and resources.

The paper concluded that the integrated BIM-GIS method is effective for planning water distribution systems. The approach offers a comprehensive view of the pipeline and its environment, leading to more informed and sustainable urban development. Future studies are suggested to extend the model's application to construction, operation, and maintenance stages, and to explore further usability in the Architectural, Engineering, and Construction (AEC) industry.

2.3 A Preliminary Contribution towards a Risk-Based Model for Flood Management Planning Using BIM: A Case Study of Lisbon *(Del Duca, 2022)*

The importance of multidisciplinary approaches in urban planning and design for reducing the effects of climate change is highlighted by this assessment of this literature, particularly for coastal cities. The amount of research in this field is increasing, but studies that integrate land and sea surveys—a critical component of effective management of coastline settlement—remain scarce. This disparity emphasizes the necessity of creative approaches, including building information modelling (BIM), to effectively control coastal risks.

The assessment delves into the possibilities of BIM as a game-changing instrument for managing coastal risks. Through the utilization of crowdsourced data, BIM enables thorough geographic and informational modelling of metropolitan regions, providing a dynamic and ever-changing framework for urban planning. This capacity is especially important for handling the changing and unpredictable characteristics of coastal areas.

to evaluate the models and approaches currently in use of coastal city planning, a thorough review is conducted.

The methodology section outlines the process adopted for risk assessment, following the European Flood Directive. It involves assessing flood risk factors, identifying exposed areas, defining possible hazards, and considering countermeasures. The study used a non-probabilistic evaluation for risk analysis, based on readily available digital cartographies from public databases. The paper also details the process of classifying flood vulnerability and the factors that influence it, such as proximity to the coastline, building construction quality, and the presence of physical barriers.

Risk management is discussed in terms of identifying risks, assigning values of exposure and vulnerability, and applying mitigation actions. The paper emphasizes the importance of reducing vulnerability levels as the most effective flood risk mitigation action. Risk prioritization is described as a process to identify severe risks and address them first, and it includes evaluations of the importance of built, natural, and intangible heritage before a flood occurs.

The paper then elaborates on City Information Modelling, focusing on interoperability and resolution, and the need for accurate geometric models and standardized information exchange requirements. It stresses the importance of setting models correctly from the beginning to avoid rework and ensure interoperability between stakeholders.

The research also includes the development of various thematic maps, such as the Existing-Terrain Map, Minimum Units Map, Exposure Map, Vulnerability Map, Safe Risk Map, and others, each serving a specific purpose in flood risk assessment and management. These maps integrate spatial and thematic data to provide a comprehensive view of the city's morphology and the prioritization of buildings and areas for action during a flood. The Priority Map is specifically mentioned as a tool to coordinate flood damage restoration operations, prioritizing residential buildings and those with high exposure and vulnerability values.

3 Methodology

3.1 Data Collection

The initial phase of the method is marked by a thorough and strategic collection of data, essential for the various stages of the endeavour. This data, pivotal for the foundation and success of the project.

The data for the thesis were collected from different governmental organisation of Munich and open-source data repositories from the internet. The major contribution of the data is from Landesbaudirektion Bayern, who are responsible for maintaining and construction of all the state buildings of Bayern, another major contribution comes from the water department of Bavaria. The data from this organisation mainly include detailed building models or IFC models, 2D CAD of the public buildings for detailed views of building plans, elevations, and sections, CityGML of LoD2 for geospatial data model represents urban objects at a specific Level of Detail (LoD2), providing crucial insights into the urban landscape of Munich, and rainfall data from opensource public websites and water department. This combination of precise architectural details and environmental data ensures a comprehensive dataset that is instrumental in driving the project forward, allowing for a nuanced understanding of the urban and environmental dynamics of the region. Each of the data and its types are explained in detail below:

Building Models : The building models are used and provided from the government organisation, Landesbaudirektion Bayern which were both in IFC and Autocad formats. The IFC format is a standardized, open file format used primarily in the building and construction industry for sharing and exchanging information about building and construction projects. Developed by BuildingSMART, a global organization working to standardize processes within the construction industry, IFC is designed to facilitate interoperability in the building industry, and it is commonly used in Building Information Modeling (BIM) (Borrmann, A., Beetz, J., Koch, C., Liebich, T., Muhic, S, 2018). The primary purpose of IFC is to enable the sharing and exchange of data between different software applications used in building and construction. This facilitates collaboration among various professionals like architects, engineers, and builders.

Also, IFC files are designed to carry a vast amount of information, including geometrical data, material properties, and spatial relationships. This makes them particularly useful for detailed analysis and simulation. As a results these models played an important role in our further simulation works.

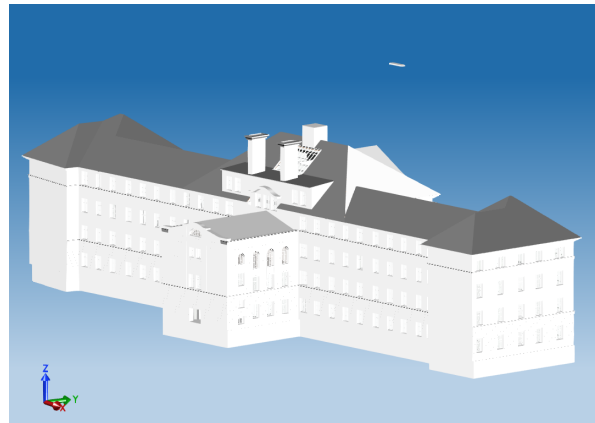


Figure 5 IFC model of Psychiatry clinic

In addition to the IFC models, we also received comprehensive CAD (Computer-Aided Design) models. These CAD models encompassed all the 2D drawings of each public hospital building within the Zimmensblock area of the LMU Hospital. The significance of these CAD drawings lies in their detailed representation of the buildings' layouts, offering a granular view of each floor plan, section, and elevation.

The CAD models were particularly notable for including benchmark and elevation points derived from local surveying data. This surveying data is crucial because it provides accurate, real-world coordinates and elevational details, essential for precise mapping and analysis. These benchmarks and elevation points are key for georeferencing – a process where points on the map are aligned with geographic coordinates in the real world. This is especially important because the provided IFC models lacked georeferencing. However we discuss about the integration and georeferencing procedure in the section 3.2.

This georeferencing not only enhances the spatial accuracy of the models but also makes them more useful for a variety of applications, in our case which is flood simulation.

Overall, the project's dataset was greatly expanded with the addition of these intricate CAD models that were enhanced with local surveying data. It made it possible to have a more thorough understanding of the Zimmensblock hospital structures, which improved modeling and design. This enhanced dataset turns into an indispensable resource for planning and analysis, guaranteeing that the project is based on precise and contextually relevant facts.

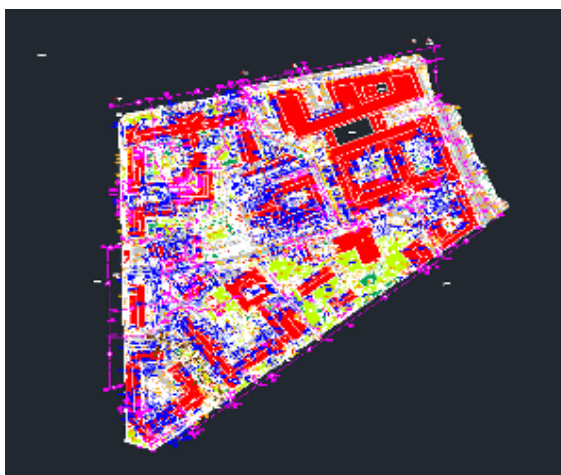


Figure 6 2D CAD model of the Zimmensblock area

Digital terrain models (DTM):

Digital Terrain Models or DTM are one of the most crucial data for our project as our end goal was to make flood scenarios and, in the end, we had to deal with understanding slopes and elevation points of the Zimmensblock area.

A Digital Terrain Model is a crucial component in the field of geospatial analysis and environmental modelling. Essentially, it represents the bare ground surface, free of any objects like vegetation and buildings. Unlike a Digital Elevation Model (DEM) which includes all surface features, a DTM specifically depicts the natural terrain and landform shapes, providing a topographical representation of the Earth's surface.

This model is generated through the collection of elevation data at various points across a landscape, often through remote sensing methods like LiDAR (Light Detection and Ranging) most likely from satellite. The DTM is then constructed by interpolating these points to create a continuous surface. It's invaluable for a wide range of applications, including watershed and drainage analysis, land-use planning, geological analysis, and infrastructure development. DTMs serve as a foundational layer in Geographic Information Systems. (*Exploring Digital Elevation models—ArcGIS Pro | Documentation, 2023*)

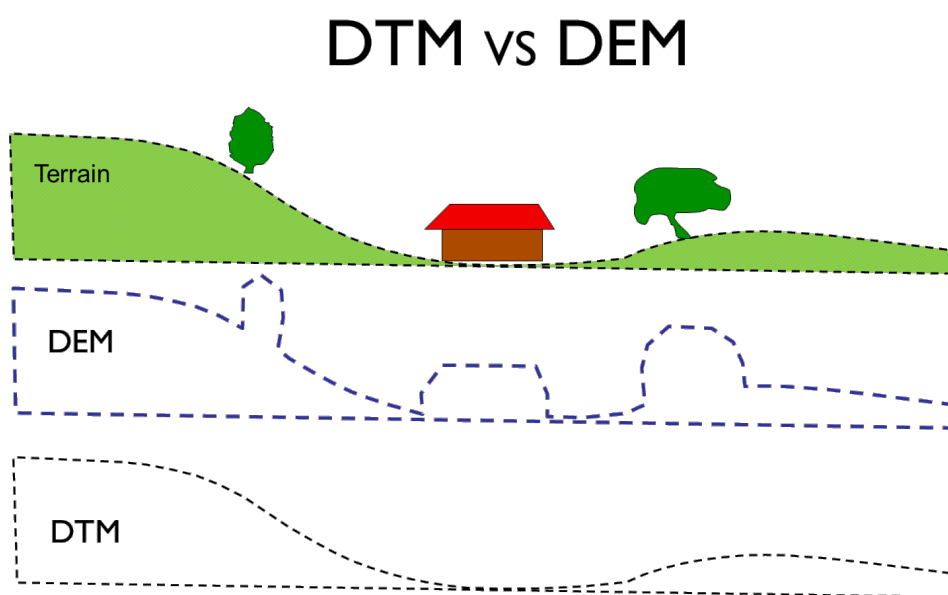


Figure 7 Different Layers in the DTM and DEM (Štular, Benjamin & Eichert, Stefan & Lozić, Edisa, 2021)

In the context of flood scenario modelling, the utilization of a Digital Terrain Model (DTM) is paramount. This tool is critical for precisely mapping and analysing the topography of an area, including slopes and elevation points. Understanding these topographical nuances is vital for comprehending how water might navigate or pool in the event of a flood. The intricacies of slopes and elevations are fundamental in dictating the direction and velocity of water flow, which are crucial components in the realm of flood modelling. By leveraging a DTM, it becomes possible to simulate a variety of flood scenarios, forecast

potential flood trajectories, and pinpoint regions that are particularly vulnerable to flooding. This advanced approach enhances our ability to prepare for and mitigate the impact of flood events.

Furthermore, DTMs allow for the integration of hydrological data and the assessment of how natural terrain channels water during heavy rainfall or similar events.

This level of analysis is crucial for developing effective flood mitigation strategies, urban planning, and infrastructure development, ensuring that the area is better prepared for potential flooding events. The use of DTMs, therefore, not only contributes to the creation of realistic and accurate flood models but also aids in making informed decisions to enhance the resilience of the Zimmensblock area against future flood risks. In discussing the project's objectives, we utilized two data sources to obtain the Digital Terrain Model (DTM). The primary source is the data provided by the local public authority, which consists of elevation details recorded by surveyors. These details are available in text files containing coordinates (latitude and longitude) along with corresponding elevation figures, which can be used to generate a TIFF file encapsulating the elevation information. The methodology for acquiring the DTM and the preparation of this data will be elaborated upon in subsequent chapters. Additionally, open-source DTM data is accessible on public websites, presented as 1-meter by 1-meter grid segments derived from satellite imagery (OpenData, 2023). While this data is readily available and in a usable format, it is important to note that DTMs based on satellite imagery may exhibit higher levels of error when compared to those created from on-the-ground surveying methods.

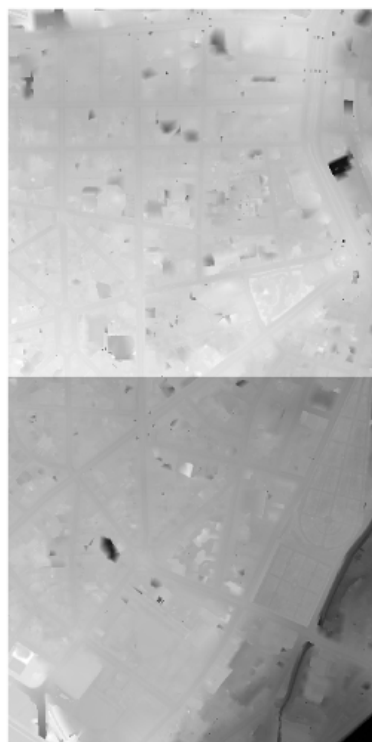


Figure 8 Elevations of the Zimmensblock area in QGIS

CityGML: The incorporation of CityGML models played a vital role in the project's success. It was impractical to obtain highly detailed models for every building due to the potential for excessive data consumption and increased security risks associated with detailed renderings. Therefore, for our purposes, we selectively used Industry Foundation Classes (IFC) for only essential buildings. For the remaining structures, we utilized CityGML models, which provide merely the height information, thereby simplifying the complexity of the models and mitigating any associated security concerns.

In short CityGML (Kolbe TH, Gröger G, 2003) is an open standardized data model and exchange format that facilitates the storage and sharing of virtual 3D city models. Developed by the Open Geospatial Consortium (OGC) (Open Geospatial Consortium, 2023), it's primarily used for urban and spatial planning, architectural and environmental simulations, and infrastructural development. Unlike traditional 2D geographical data formats, CityGML includes the geometry, topology, semantics, and appearance of city-related objects, such as buildings, roads, rivers, and vegetation, providing a multi-dimensional and multi-level representation of urban objects. It supports different Levels of Detail (LoDs), ranging from simple block models to detailed architectural models, making it

incredibly versatile for various applications. Its open format encourages interoperability, enabling various stakeholders, including urban planners, architects, and government bodies, to collaborate effectively using shared models. This facilitates more informed decision-making and efficient management of urban environments.

These LoDs mentioned above range from basic, block-like shapes to highly detailed architectural models, each serving different purposes and complexities in urban modelling.

LoD0: This is the most basic level, representing the city model as a 2.5D terrain model (a flat surface) with footprints of buildings. It's typically used for regional planning and large-scale urban studies where building heights are not critical.

LoD1: At this level, buildings are represented as block models with a uniform height. This provides a rough but quick visualization of the urban landscape, useful for medium-scale city modelling, such as urban zoning and sunlight studies.

LoD2: Here, buildings are modelled with differentiated roof structures, giving a more realistic representation of the cityscape. LoD2 is often used for shadow analysis, noise propagation studies, and basic architectural visualization.

LoD3: This level includes detailed architectural models with precise facades. It's suitable for detailed urban and environmental analysis, like microclimate studies, and is often used in detailed city planning and heritage conservation.

LoD4: The highest level of detail, LoD4, includes interior building structures like rooms, stairs, and furniture. It's primarily used for indoor navigation, emergency response planning, and detailed building analysis.

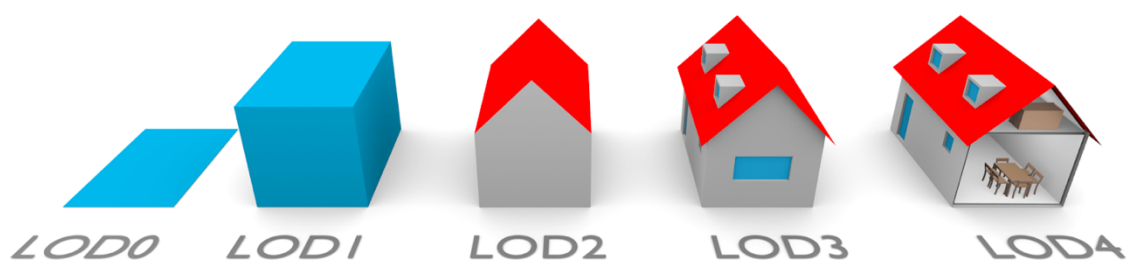


Figure 9 Different Level of Detail as in CityGML (An Improved LOD Specification for 3D Building Models, 2016)

In summary, the integration of CityGML models alongside selective IFC models for critical buildings in the project represented a strategic approach that balanced detail, data management efficiency, and practicality. Specifically, the CityGML models were utilized at Level of Detail 2 (LoD2), (as also provided by the Landesbaudirektion) which provided a more realistic representation of the cityscape with differentiated roof structures. This level of detail was sufficient to capture the essential aspects of the urban environment without the complexity and security concerns of higher-detail models. This methodology provided a robust framework for the project, ensuring that the urban model was both detailed and functional, catering to the specific requirements of the flood analysis and planning objectives.



Figure 10 CityGML LoD2 of the Zimmensblock area

3.2 Data Preparation

Upon completing our data collection, we proceeded to the data preparation phase. This stage involved converting the collected data into a suitable format for subsequent analysis and simulation. The preparation process for each dataset is detailed individually in the following sections. But first, let's introduce the software applications and programming languages utilized during the data preparation phase:

Autodesk AutoCAD: AutoCAD, a prominent software by Autodesk, is widely used in architecture, engineering, and construction for its robust computer-aided design (CAD) capabilities. It allows for the creation of precise 2D and 3D drawings, revolutionizing the design process by replacing manual drafting with an efficient, automated method.

Known for its user-friendly interface, AutoCAD supports a wide range of design tasks, from simple geometric shape creation to complex architectural plans. Its compatibility with various file formats and integration with other Autodesk products make it an indispensable tool in the design and drafting industry.

So, basically this software helped in understanding and cleaning the data we have got from the public authorities and filter out the relevant items and layers which were relevant to our simulation and analysis.

Autodesk Revit: Revit, developed by Autodesk, is a powerful Building Information Modelling (BIM) software widely used in the architecture, engineering, and construction industries. It allows professionals to design buildings and structures in 3D, annotate the model with 2D drafting elements, and access building information from the building model's database. Revit is highly valued for its collaborative features, enabling multiple team members to work on a single project simultaneously and share updates in real time. Its advanced tools for modelling, coordination, and simulation facilitate efficient planning, design, and management of building projects. Revit's focus on BIM helps in creating intelligent models that represent the functional characteristics of a building, offering a holistic approach to building design and management.

In our approach Revit played an important role in cleaning the IFCs and as importing to IFC and editing the same gets relatively easier in Revit so it was as the choice to choose Revit over any other BIM software.

QGIS: QGIS, also known as Quantum GIS, is a sophisticated open-source Geographic Information System (GIS) platform renowned for its comprehensive spatial analysis and cartographic functionalities. The software is lauded for its intuitive interface, versatile nature, and expansive suite of tools that empower users to efficiently analyse and depict spatial information ("Welcome to the QGIS Project!", 2023).

A pivotal feature of QGIS pertinent to our project is its georeferencing capability, which is essential for calibrating spatial data with specific geographic coordinates.

In the context of integrating QGIS with BIM applications such as Revit, georeferencing is of paramount importance. Our project primarily utilized data in IFC format; however, these models frequently require precise positioning within a geographic framework. QGIS facilitates this by enabling the georeferencing of Revit models, allowing for the meticulous superimposition of intricate building designs onto specific geographic locales. This meticulous alignment ensures that structures modelled in Revit are accurately mapped out in relation to their actual spatial coordinates, bearing, and proportions.

Autodesk Civil 3D: A prominent civil engineering design software which is tailored for infrastructure design and documentation. It is widely used for projects involving land development, transportation, and environmental planning.

One of the key features of using Civil 3D in our thesis is its advanced georeferencing capabilities. Georeferencing in Civil 3D involves aligning the design elements to real-world coordinates, which is essential for accurate planning and AutoCAD models that were provided from the government authorities. This feature allows users to import geospatial data, such as topographical maps and satellite imagery (what we used here was OSM) and use it as a reference. The software can handle various coordinate systems and geospatial formats, ensuring compatibility and precision.

Lastly, 3D city database developed by the Geoinformatics chair of the Technical University of Munich is also used for visualising and preparing the CityGML data.

Step 1: Data preparation starts with filtering and keeping only data which are relevant to our application. The AutoCAD is used in this process. In the process of cleaning, we extract the elevation information from the AutoCAD file additionally we filter the model based in layers and relevant buildings that we want to keep. Few of the items like vegetation and green infrastructures were removed from the drawing in order to reduce the complexity as it was not relevant to our analysis. Lastly dimensions were noted, and relevant building were made into a separate layer to use those later for better georeferencing.

Step 2: This step involves in exporting the cleaned filtered AutoCAD model into Civil3D for georeferencing. Georeferencing in Civil 3D is a process that ensures the accurate alignment of CAD drawings with real-world geographic coordinates, using several key concepts. It begins with the selection of an appropriate coordinate system, which lays the foundation for defining locations on Earth's surface, for example to be WGS 84 for our case. The process then utilizes control points - specific locations in the drawing with known real-world coordinates - as anchors for alignment which is taken from the surveyor data with known points and benchmarks. The software performs transformations, including translation, rotation, and scaling, based on these control points to align the drawing accurately. Further refinement is achieved through rubber sheeting, a method that stretches or compresses parts of the drawing for a better fit, especially useful on irregular terrains. Underpinning this process are the concepts of projection and datum; the projection translates the Earth's three-dimensional surface to a two-dimensional map, while the datum defines the Earth's shape and size reference model. Ensuring that both the CAD drawing and the base map use the same projection and datum is crucial for accurate alignment. This combination of spatial reference components, including the coordinate system, projection, and datum, allows Civil 3D to accurately place and orient the CAD drawing in a true three-dimensional spatial context.

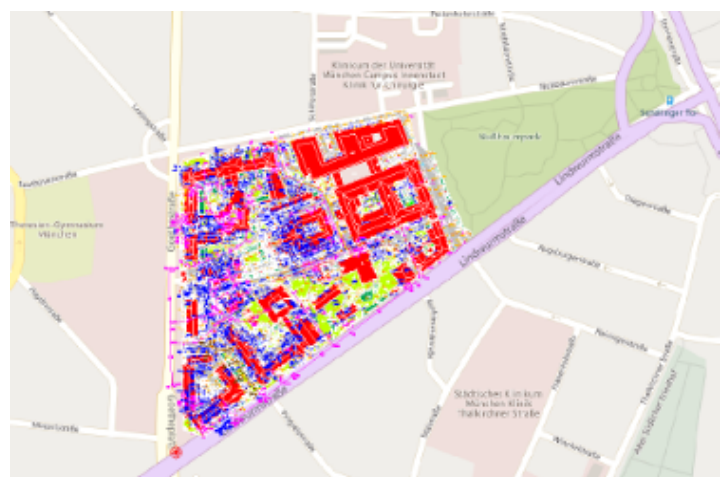
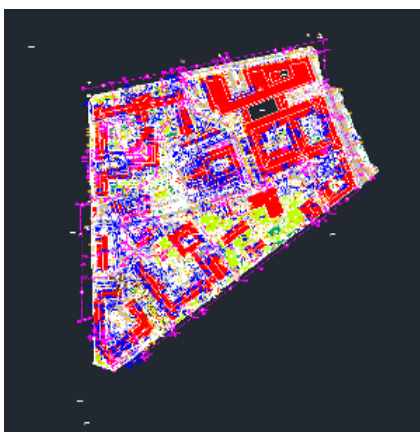


Figure 11 Georeferenced CAD model in Civil3D

Conversely, our individual architectural models were procured in IFC format. These models were imported into Autodesk Revit for refinement and optimization. Employing a consistent methodology, we isolated only the pertinent architectural elements for retention and excised the superfluous details. The received IFC models lacked geospatial referencing, necessitating the implementation of georeferencing techniques. To ensure precision, we subjected the IFC models to georeferencing through two distinct methods, which are delineated below.

Method 1: This method includes the use of ArcGIS Pro and specialized plugins or tools designed to facilitate the integration of BIM data into GIS. It is also possible to open the IFC file in Revit. This could involve translating the BIM data into a feature class or a 3D model that can be used within ArcGIS Pro.

If the IFC model does not come with inherent geospatial coordinates, one needs to manually georeference it (*BIM And GIS Integration | Models & Maps Working Together*, 2023). Initially an AOI is drawn on the map tile at ArcGIS pro, upon which the IFC would be placed. This involves aligning the model with a base map or other geospatial data within ArcGIS Pro. One might use reference points in both the IFC model and the base map to align them accurately.

These reference points could be from the surveyor data or already know points from the previous AutoCAD file. After the initial alignment, fine-tuning adjustments are sometimes necessary to ensure that the model precisely matches the real-world location. This could involve moving, rotating, or scaling the model within the GIS environment.

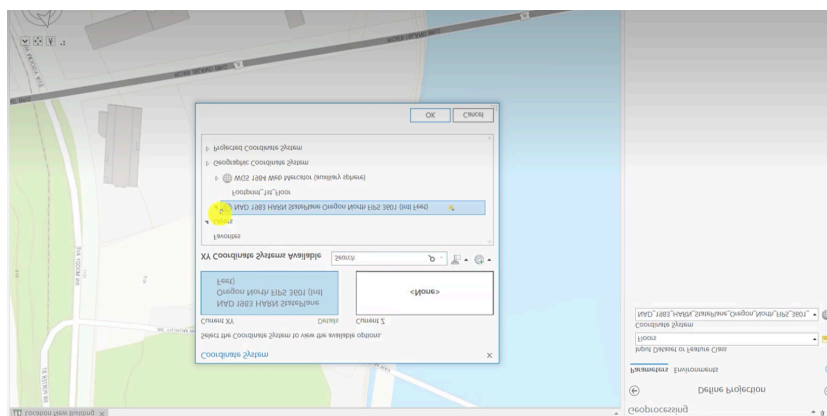


Figure 12 Georeferencing IFC in ArcGISPro

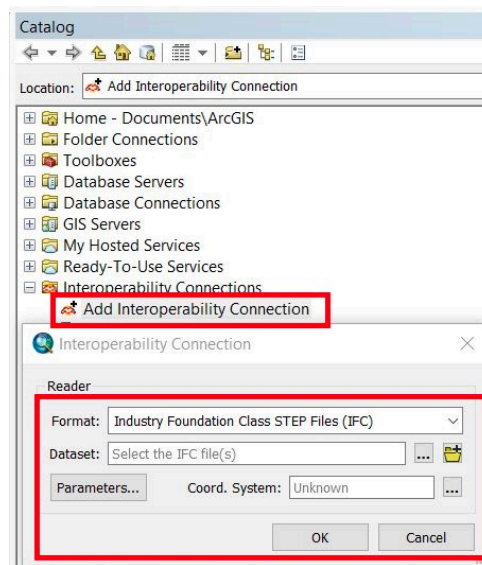


Figure 13 Georeferencing IFC in ArcGIS Pro

Method 2: The Second method includes the use of IFCopenshell (*IfcOpenShell - the Open Source IFC Toolkit and Geometry Engine, 2023*). *IfcOpenShell* is open-source library that provides tools for working with IFC data, such as viewing, editing, and converting. This can include tasks like extracting information from an IFC file, modifying IFC models, or converting IFC files into other formats. A major challenge in automating IFC data processing is the lack of explicit georeferencing information in IFC exchanges. There are two typical scenarios:

Local Reference System: Commonly in construction projects, a shared local reference system is used, defined by a local origin and axis orientation. The local origin is usually a prominent point near the site, and the axis orientation is selected for practical reasons, like aligning with the main construction axis. Although the geographical location of this local system is known among the project partners, it's often not included in the IFC file.

Geospatial Reference System: In some projects, IFC files are exchanged using a standard projected reference system recognized by land surveyors or in geospatial data, such as EPSG:2169. This geospatial information, while known to project participants, is typically not explicitly mentioned in the IFC file, which hinders automated processing capabilities.

In each of these scenarios, the issue of missing georeferencing information can be addressed by utilizing the `IfcProjectedCRS` and `IfcMapConversion` entities from the IFC4 standard. The `IfcProjectedCRS` entity is used to define a known, target coordinate reference system (CRS). On the other hand, the `IfcMapConversion` entity is employed to outline the necessary coordinate transformation for converting coordinates from the project's CRS to the designated target CRS. As illustrated in the following diagram from the IFC standard, these specific IFC entities are directly linked to the `IfcProject` entity, which is a subclass of `IfcContext`. (Stijngoedertier, 2023)

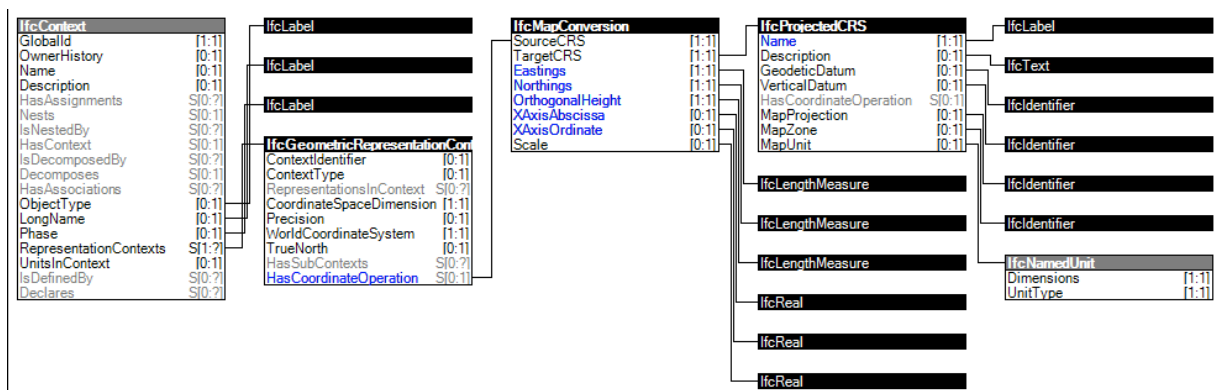


Figure 14 Diagram of georeferenced IFC in IFCopenshell

The next task involves in preparing the digital terrain model, which could also be achieved by two methods. The first method involves the use of the available elevation data from surveyors as found in the AutoCAD model. The elevation file provided was a text file consisting of northing and eastings of projected coordinate system (like UTM - Universal Transverse Mercator). So, after the coordinate system is found the file is converted into relevant latitude and longitude with its subsequent elevation. Once the spatial data is created it can be saved as a TIFF file, particularly a GeoTIFF, which is a popular format for storing georeferenced raster imagery. GeoTIFF files contain metadata tags (like `ModelPixelScaleTag`, `ModelTiepointTag`, and `GeoKeyDirectoryTag`) that store the geospatial data, ensuring that the image aligns correctly with geographic maps.

However, another approach is using already available DTM that are publicly available in government sites, which includes this elevation information. However, it's not much accurate as the previous approach as in this method it is done by satellite imagery. Although in our case we have used both methods, the first method is used for our main area of interest where we need maximum accuracy and the opensource data is used for the neighbouring areas. Lastly all these tiff files are stitched together in one final TIFF file using QGIS.

```
from pyproj import Transformer

# Transformer for converting UTM Zone 32N (EPSG:32632) to WGS84 (EPSG:4326)
transformer = Transformer.from_crs("epsg:32632", "epsg:4326", always_xy=True)

# Function to process the file and convert coordinates
def process_file(file_path):
    with open(file_path, 'r') as file:
        for line in file:
            easting, northing, elevation = map(float, line.split())
            lon, lat = transformer.transform(easting, northing)
            print(f"Latitude: {lat}, Longitude: {lon}, Elevation: {elevation}m")
```

```
Latitude: 48.12612193875446, Longitude: 11.558337046840641, Elevation: 522.33m
Latitude: 48.12613092676394, Longitude: 11.558337493495506, Elevation: 522.34m
Latitude: 48.126130627728834, Longitude: 11.558350918506656, Elevation: 522.34m
Latitude: 48.12614021380702, Longitude: 11.55832451513688, Elevation: 522.35m
Latitude: 48.12613991477339, Longitude: 11.558337940150587, Elevation: 522.36m
Latitude: 48.12613961573818, Longitude: 11.558351365164075, Elevation: 522.39m
Latitude: 48.12613931670141, Longitude: 11.558364790177343, Elevation: 522.38m
Latitude: 48.126149500848705, Longitude: 11.558311536773582, Elevation: 522.37m
```

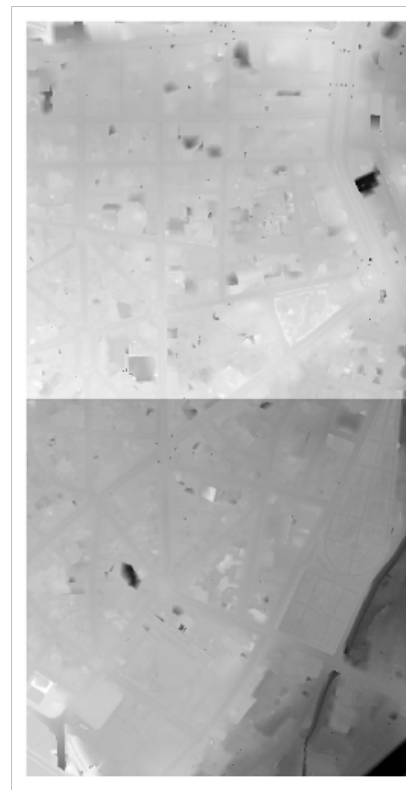


Figure 15 Converting Elevation into TIFF images.

3.3 Integration

3.3.1 Model Integration

The process of integrating all models begins by combining individual components, such as the IFC models, CityGML, and digital terrain models, into a single, unified model, which we refer to as Model X. The primary objective of creating Model X is to facilitate the incorporation of additional hydrological models and data within the model. To simplify this integration process, Autodesk InfraWorks was utilized as the software of choice.

Autodesk InfraWorks is a comprehensive planning and design platform that enables engineers and designers to create, evaluate, and communicate infrastructure projects effectively. It offers a range of tools for 3D model generation, analysis, and visualization, making it ideal for large-scale infrastructure projects such as roadways, bridges, airports, and urban development. InfraWorks stands out for its ability to integrate with various data sources, including GIS, topographical, and satellite data, enabling users to work with real-world context. This integration allows for more accurate and realistic representations of proposed projects, facilitating better decision-making. Additionally, the software's user-friendly interface and collaboration tools enable professionals from a variety of disciplines to access it, fostering efficiency and teamwork in the creation of challenging infrastructure projects. With Autodesk InfraWorks, users can anticipate project challenges, explore alternatives, and visualize the impact of their designs long before physical construction begins. By importing IFC models into InfraWorks, professionals can integrate detailed architectural and structural elements into their infrastructure projects, ensuring a holistic approach to design and planning. This integration is particularly beneficial in complex projects where the interaction between buildings and surrounding infrastructure is critical.

The combination of IFC models and DTM in InfraWorks enabled to visualize how proposed infrastructure will interact with existing buildings and the natural terrain. This approach enhances decision-making, improves risk management and more accurate simulation, and ensures that the infrastructure is designed in harmony with its surrounding environment, ultimately leading to more sustainable and efficient project outcomes.

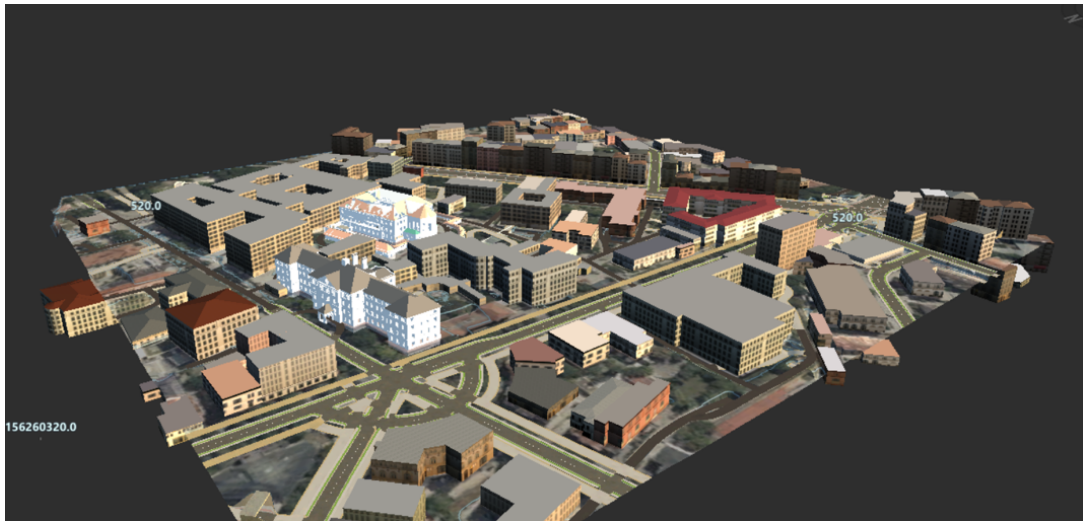


Figure 16 Model X in Infraworks

In order to align all our models which were already georeferenced from the above steps we needed to import into a common project which are done by basic four steps:

Coordinate Systems and Projection: InfraWorks supports various coordinate systems and projections (*Import GIS Content into Autodesk InfraWorks, 2023*) to accurately represent the earth's curved surface on a flat map. Users can select any appropriate coordinate system based on the project's geographic location. This might be a global system like WGS 84, which was our case.

Importing Geospatial Data: All the geospatial data from different sources like GIS tiff files, IFCs, CAD files are imported. This data typically contains embedded spatial information, including coordinates and projection details.

Aligning Data with Earth's Surface: When importing data, InfraWorks reads the embedded geospatial metadata to place the data accurately on the earth's surface. If the data lacks geospatial metadata, we can also manually georeference it by aligning known points in the dataset with corresponding points on a base map or by entering specific coordinates, however in our case we already had it set.

Data Integration and Visualization: Once the data is georeferenced, InfraWorks integrates it into a unified 3D model.

This integration allows for the overlay of different data types (like terrain models, road networks, and building models) in their accurate geographic positions and our model is ready for simulation.

This model is further exported into object file which is later made ready for our simulation. For the process of further visualisation blender is used.

3.3.2 Hydrological Data Integration

Hydrological data was collected from the water department of Bavaria, and from their official website. These data were used for the flood simulation and ground water modeling as these data was used for making precipitation hydrograph from the previous rainfall data that would be explained in detail.

Table 1 Historical Rainfall data

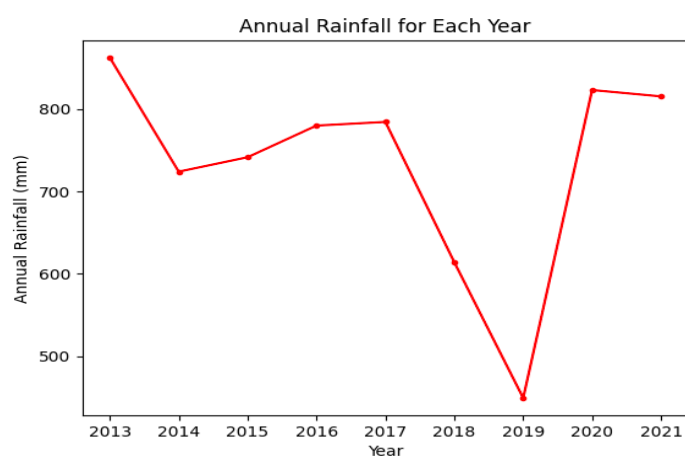
1366_01.01.2013_31.12.2022_tmw

Quelle:	Bayerisches Landesamt für Umwelt, www.gkd.bayern.de		
Datenbankabfrage:	12.10.2023 16:18		
Zeitbezug:	MEZ		
Messstellen-Name:	Finsing		
Messstellen-Nr.:	1366		
Ostwert:	708093	Nordwert:	5344650 ETRS89 / UTM Zone 32N
Datum	Niederschlag [mm]	Prüfstatus	
2013-01-01	1,30	Geprueft	
2013-01-02	0,00	Geprueft	
2013-01-03	2,70	Geprueft	
2013-01-04	17,60	Geprueft	
2013-01-05	6,20	Geprueft	
2013-01-06	1,40	Geprueft	
2013-01-07	0,60	Geprueft	
2013-01-08	1,40	Geprueft	
2013-01-09	0,60	Geprueft	
2013-01-10	1,10	Geprueft	
2013-01-11	1,20	Geprueft	
2013-01-12	2,40	Geprueft	
2013-01-13	0,00	Geprueft	
2013-01-14	0,10	Geprueft	

The above chart explains the rainfall data for each day from 2013 to 2022 in mm which was used to construct the unit hydrograph and understanding the worst rainfall scenario for flood simulation.

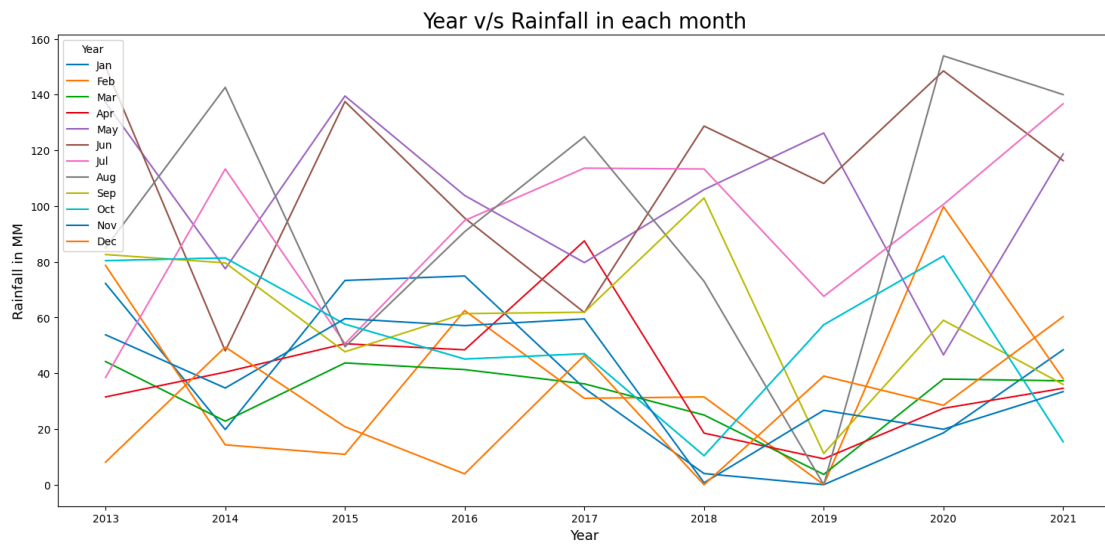
The trend of annual rainfall over the span of ten years, from 2013 to 2022. Initially, the rainfall appears to decrease from 2013, reaching its lowest point in 2015. Following this, there is a slight increase in 2016 before a significant drop occurs in 2019, marking the lowest annual rainfall within the observed period. However, the subsequent years show a recovery, with 2020 experiencing a modest rise followed by a sharp increase. The trend continues upward, peaking in 2020. The graph concludes with a slight decrease in rainfall in 2021, yet the levels remain high compared to the middle of the decade. This visual data suggests a variable pattern of rainfall with significant fluctuations, highlighting years of both drought and abundance.

Table 2 Annual Rainfall for Each Year



When the trend of day wise monthly rainfall patterns was studied over the course of ten years, from 2013 to 2022. Each line in the below graph represents a different month, identified by unique colours, plotting the variability of rainfall in millimetres (mm). The data shows considerable fluctuation in rainfall from month to month and year to year, with no clear consistent pattern across the years. Some months, such as those represented by the pink and grey lines, exhibit sharp peaks and troughs, indicating significant variability in rainfall for those months over the years. In contrast, other months show more modest variations. Overall, the graph depicts a complex interplay of rainfall amounts, with some years experiencing higher peaks or lower troughs in certain months, highlighting the unpredictable nature of monthly rainfall distribution over nearly a decade.

Table 3 Year v/s Rainfall in each month



Software used in simulation:

HEC-RAS:

HEC-RAS, which stands for Hydrologic Engineering Centres River Analysis System, is a software program developed by the U.S. Army Corps of Engineers for modelling the hydraulics of water flow through natural rivers and other channels. The primary function of HEC-RAS is to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels. The system is capable of handling both steady water flow (constant flow over time) and unsteady water flow (changing flow over time), and it can analyse conditions such as water surface profiles, sediment transport, and water quality (Novrima, 2023).

HEC-RAS is widely used for floodplain management, supporting the design and analysis of floodplain delineation, flood risk assessment, and for planning flood damage reduction measures. It can simulate various hydraulic conditions, including the calculation of water surface profiles under different flow rates, bridge and culvert effects, levee and floodplain storage, and the impact of structures like weirs and gates on flow patterns.

The software's flexibility and extensive capabilities make it a standard tool in hydraulic engineering and a critical component in the development of flood risk management solutions worldwide.

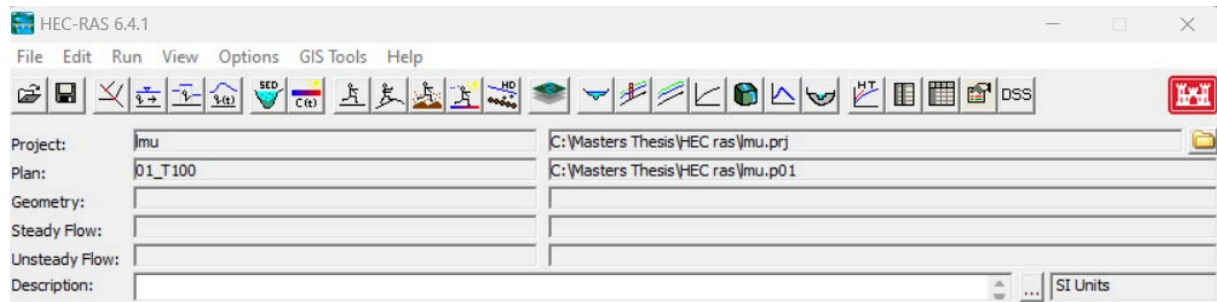


Figure 17 HEC-RAS Dashboard

HEC-RAS performs hydraulic calculations by utilizing established physical equations and numerical methods to simulate the behaviour of water in channels and floodplains. The calculation involved are explained below:

Energy Equation: HEC-RAS employs the energy equation, which is based on Bernoulli's principle, for steady flow analysis. It compares the energy at different catchment area cross-sections while considering variables like channel slope, frictional resistance (Manning's equation), and elevation and velocity variations. Water surface profiles are calculated using the energy equation and are crucial for figuring out flood levels.

Momentum Equation: In unsteady flow analysis, both the conservation of momentum and energy are applied to capture the dynamic behaviour of changing flows. The momentum equation considers the effects of friction, pressure, and gravity on the acceleration and deceleration of water in a channel.

Continuity Equation: The volume of water entering a system must match the volume leaving the system, minus any losses or gains inside the system. This equation illustrates the conservation of mass. When calculating unsteady flow in HEC-RAS, the continuity equation is utilized in conjunction with the momentum equation to ascertain the evolution of flow depth and velocity.

To perform these calculations, HEC-RAS requires detailed input data such as geometry, flow data, channel roughness coefficients, and boundary conditions. The software discretizes the catchment into a series of interconnected cross-sections for 1D analysis or

into a grid for 2D analysis. Numerical methods such as finite difference or finite volume methods are then used to solve the equations across these sections or grids, iterating towards a solution that describes the flow conditions for each time step in the simulation. HEC-RAS is extensively used in rainwater flood simulation to predict how rainfall events might affect river systems and floodplains which is the motive of our project. By integrating rainfall data which are explained above, coupled though hydrologic model like HEC-RAS can simulate the response of precipitation inputs. The process begins with the creation of a detailed geometric model of the channel and the surrounding floodplain, incorporating elements that can influence the flow pattern.

Once the geometric model is established, HEC-RAS uses rainfall data (typically in the form of hydrographs) to simulate how rainwater will enter the river system and move downstream. This may involve converting rainfall intensity into runoff using a separate hydrologic model, which then provides input flows for the hydraulic model. HEC-RAS takes these flows and computes water surface profiles for the river system, using its steady or unsteady flow analysis capabilities.

For unsteady flow simulations, which are particularly relevant for rainwater flooding events, HEC-RAS calculates the changes in water levels and flow velocities over time, providing a dynamic picture of the flooding process. The model can simulate the timing, depth, and extent of flooding across the floodplain, considering complex interactions between the inflow from rainfall, the channel geometry, and any existing flood control structures. By employing these simulations, HEC-RAS helps engineers and floodplain managers to assess flood risks, design and evaluate flood mitigation measures, and plan emergency responses. It also allows for the examination of different scenarios, such as changes in land use or climate change impacts, which can alter the behaviour of rainwater runoff and flood dynamics. The ability to accurately model rainwater flooding is crucial for developing strategies to protect communities and reduce the economic and environmental impact of flood events (Armain, 2021).

The methodology of the flood simulation involved the following steps:

- The terrain is loaded in the RAS mapper, for the terrain we have used the elevation data derived in the previous chapter. The elevations are provided in the left

side of the provided map. From the terrain map we can understand the north-west the greenish yellow path of our area of interest is having some lower elevation, however the southwest region is having higher elevation.

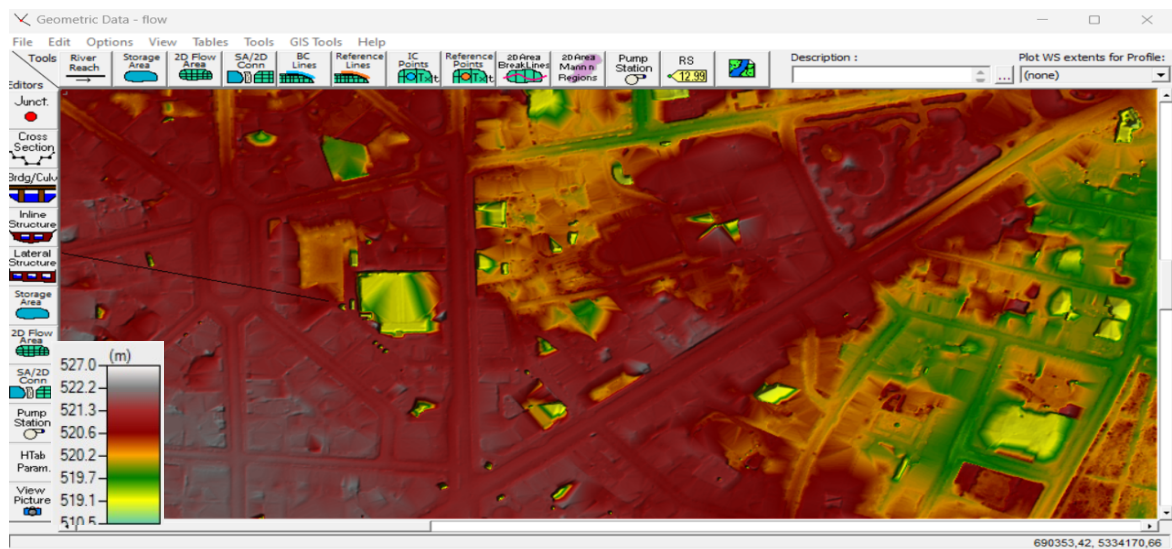


Figure 18 Elevations in HEC-RAS

- The second step is importing the area of interest as a shape file.
- Proceeding to a crucial stage, this involves sketching out the flow regions, incorporating them with a boundary condition delineation. Initially, one outlines the periphery, closely matching our targeted zone, and then proceeds to establish the mesh. A more refined mesh generally yields improved outcomes, albeit at the expense of increased computational time. It's noteworthy to acknowledge the creation of a minor discharge point in the northwest segment of the target area, predicated on the presumption that water will gravitate towards this specific zone due to its being the lowest elevation across the plot.

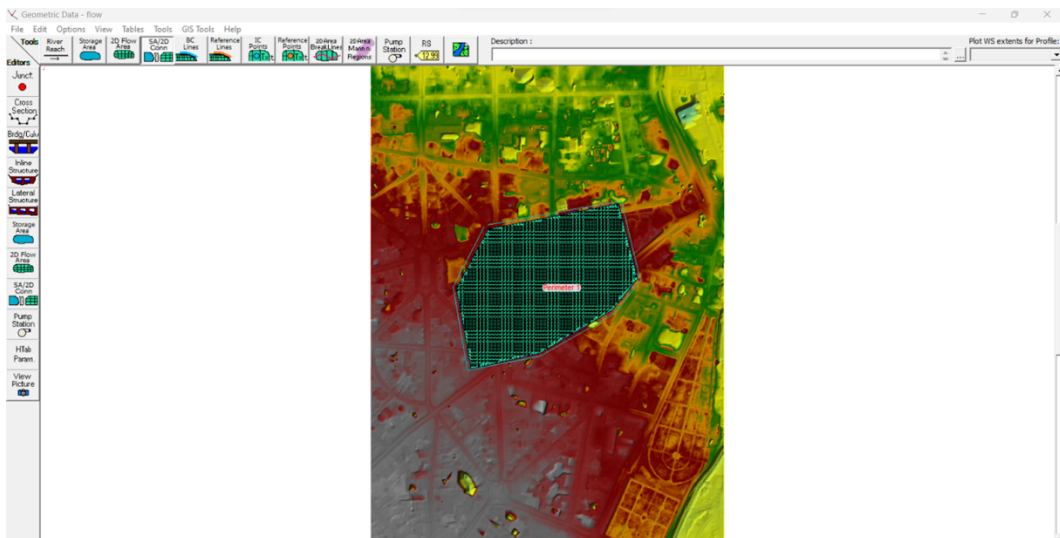


Figure 19 Catchment area for our area of interest

- The fourth step involves the setting of boundary conditions as shown in the UI of HEC-RAS.

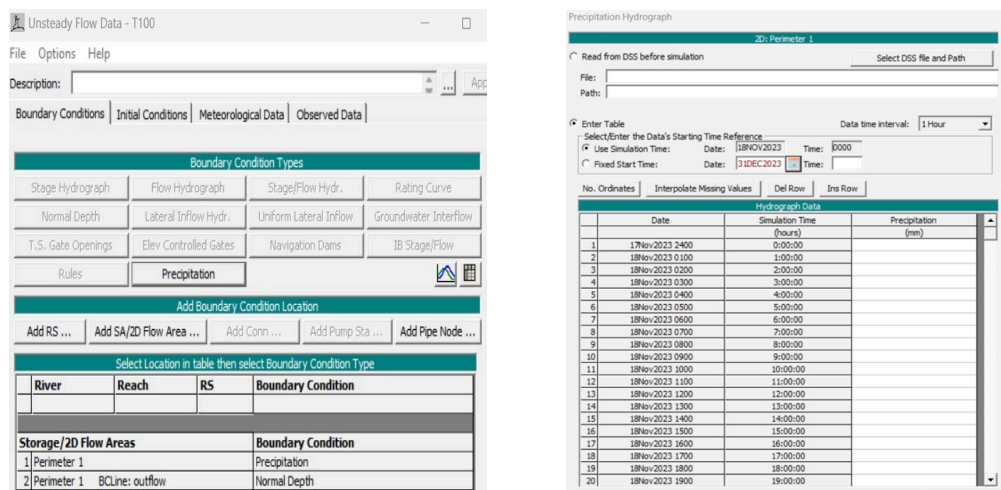


Figure 20 Boundary conditions as set in HEC-RAS

- The precipitation chart is also added into the HEC-RAS as shown in the previous chart and simulation time are also added.

The final step involves in setting values and coefficient which is important for the accuracy of the simulation.

Additional web software for Quick simulations:

For quick simulations Fast Flow App could be used. This app typically serves as a critical resource for communities in flood-prone areas, offering real-time data on water levels, weather forecasts, and flood warnings. The core functionality of Fast Flow centres around its ability to collect and disseminate information quickly, allowing users to make informed decisions during potential flood events.

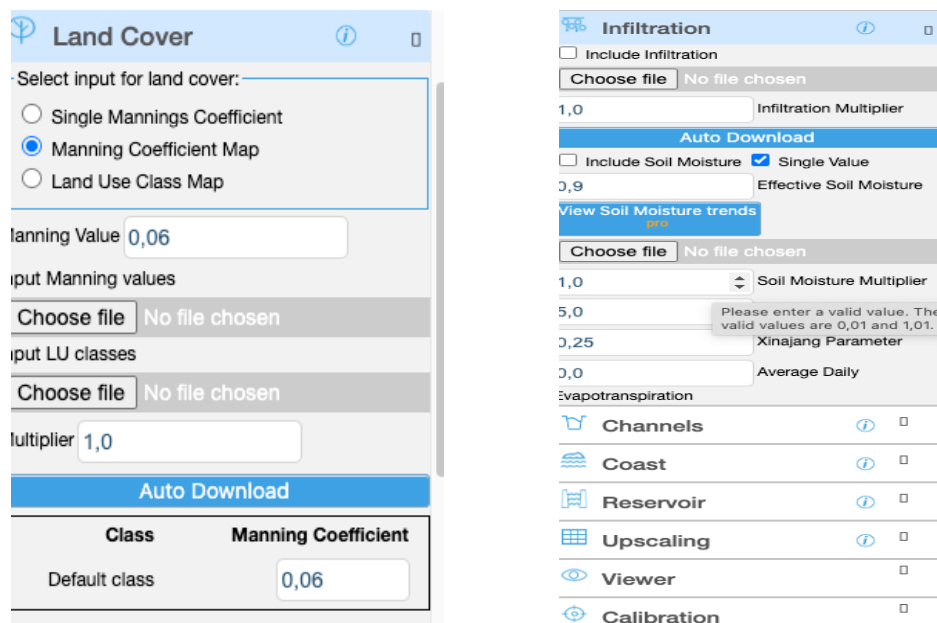


Figure 21 Interface as in Fast Flow application

The DEM we use here is same as what we derived previously, and we make the rainfall intensity from the unit hydrograph following the same procedure. Here we also consider infiltration, soil characteristics and channel information to make our simulation more accurate.

Estimating the Flow parameters:

Calculating rainfall intensity:

Rainfall intensity refers to the rate at which rain falls during a storm. It is usually measured in millimetres per hour (mm/hr).

This data can be derived from the historical data that we got from the public authorities. Rainfall intensity is an important factor in hydrology and water resource management, as it affects runoff, infiltration, erosion, and flood potential.

Table 4 Rainfall intensity from historical data

	Datum	Niederschlag [mm]	Prüfstatus	Rainfall Intensity (mm/hr)
0	2013-01-01	1.3	Geprueft	0.054167
1	2013-01-02	0.0	Geprueft	0.000000
2	2013-01-03	2.7	Geprueft	0.112500
3	2013-01-04	17.6	Geprueft	0.733333
4	2013-01-05	6.2	Geprueft	0.258333

The above chart explains the rainfall intensity of each day based on hourly readings, The worst (highest) rainfall intensity over the years in the dataset occurred on June 14, 2015, with an intensity of 3.66 mm/hr. This value represents the maximum hourly rainfall intensity calculated from the daily data and we use this for our analysis.

In addition to the intensity of the rain, there are several other factors to consider, such as the Rainfall Multiplier, the duration of the rainfall, and the shape of the rainfall. The Rainfall Multiplier is a coefficient applied to modify the intensity for computational reasons, and in this instance, it is set to "1". The Rain Shape pertains to how the intensity of the rain is spread throughout the event, which is closely linked to its duration. This distribution can either be consistent (flat) or exhibit peaks.

Rainfall intensities based on return periods:

Understanding rainfall intensities based on return periods is essential for a myriad of reasons spanning infrastructure design, flood risk management, urban planning, agriculture, climate change adaptation, and economic strategies. Such data enables engineers to design resilient infrastructure capable of withstanding extreme weather, helps in identifying flood-prone areas for effective risk management, guides urban development in a manner that minimizes flood risks, and is vital for agricultural planning and water resource management (Del Duca et al., 2022). Additionally, in the face of climate change, it offers a basis for adapting infrastructure and planning strategies to cope with altered

precipitation patterns. For the insurance sector and governmental economic planning, it provides a critical tool for assessing risk and preparing financially for disaster response and recovery. In sum, rainfall intensity and return period data are indispensable for safeguarding communities, ensuring sustainability, and enhancing resilience against extreme weather events.

Table 5 Statistical data from KOSTRA

KOSTRA 2020 Niederschlagshöhen in mm									
D \ T	1 Jahr	2 Jahre	3 Jahre	5 Jahre	10 Jahre	20 Jahre	30 Jahre	50 Jahre	100 Jahre
5 min	7,1	8,6	9,5	10,7	12,4	14,2	15,4	16,9	19,1
10 min	9,6	11,6	12,9	14,5	16,8	19,3	20,8	22,9	25,9
15 min	11,3	13,6	15,1	17,0	19,7	22,6	24,4	26,8	30,3
20 min	12,5	15,1	16,7	18,9	21,9	25,1	27,1	29,8	33,7
30 min	14,5	17,4	19,3	21,7	25,3	28,9	31,2	34,4	38,8
45 min	16,6	20,0	22,1	24,9	28,9	33,1	35,8	39,4	44,5
60 min	18,2	22,0	24,3	27,4	31,8	36,3	39,3	43,2	48,8
90 min	20,7	25,0	27,6	31,1	36,2	41,4	44,8	49,2	55,6
2 h	22,7	27,4	30,3	34,1	39,6	45,3	49,0	53,9	60,9
3 h	25,7	31,1	34,4	38,7	45,0	51,4	55,6	61,2	69,1
4 h	28,1	34,0	37,6	42,3	49,1	56,2	60,8	66,9	75,5
6 h	31,9	38,5	42,6	47,9	55,7	63,7	68,9	75,8	85,6
9 h	36,1	43,6	48,2	54,3	63,1	72,1	78,0	85,8	96,9
12 h	39,4	47,6	52,6	59,3	68,9	78,8	85,2	93,7	105,8
18 h	44,6	53,9	59,6	67,1	77,9	89,1	96,5	106,1	119,8
24 h	48,7	58,8	65,0	73,3	85,1	97,3	105,3	115,8	130,8
48 h	60,2	72,6	80,3	90,5	105,1	120,2	130,1	143,0	161,5
72 h	68,1	82,2	90,9	102,4	118,9	136,0	147,2	161,8	182,8
96 h	74,3	89,7	99,2	111,7	129,8	148,4	160,6	176,6	199,5
120 h	79,5	96,0	106,2	119,6	138,9	158,9	171,9	189,0	213,5
144 h	84,1	101,5	112,2	126,4	146,8	167,9	181,7	199,8	225,7
168 h	88,1	106,3	117,6	132,5	153,9	176,0	190,4	209,4	236,5

Index_RC: 203167
 Zeile: 203
 Spalte: 167
 KOSTRA-DWD-Rasterfeld

Projektort:

From the KOSTRA data we conclude the best is use 10-year return period data of 60 min duration, generally in sewage planning 5 years of return period is considered however in our case we consider 10-year return period considering climate changes.

Precipitation Hydrograph: A precipitation hydrograph is the graphical representation of the rate of rainfall over a specific period. It plots the intensity of precipitation (usually in millimetres per hour against time. The key aspects of a precipitation hydrograph are given below.

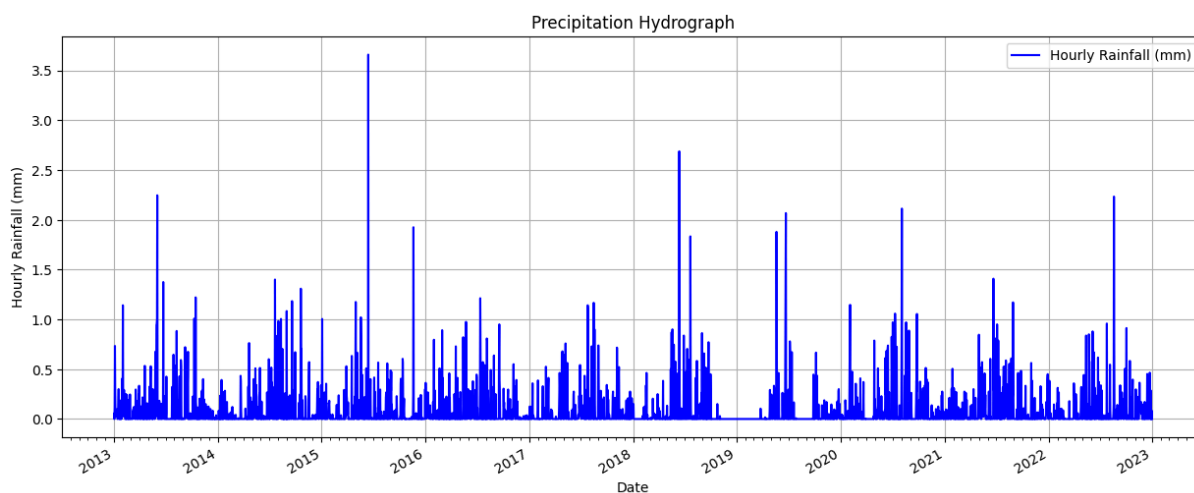
Time Axis: The horizontal axis (x-axis) represents time. The time scale can vary depending on the purpose of the hydrograph - it can span hours, days, or even months.

Rainfall Intensity Axis: The vertical axis (y-axis) shows the intensity of precipitation, typically measured in millimetres per hour (mm/hr).

Precipitation hydrographs are generally used to analyse the pattern of rainfall over a period. They are essential in hydrology for understanding and managing water resources, predicting potential flooding events, designing drainage systems.

Difference from Hydrographs: It's important to distinguish precipitation hydrographs from discharge hydrographs, which plot the flow rate of water in a stream or river over time. While a precipitation hydrograph deals with the input of water (rainfall), a discharge hydrograph deals with the output or movement of water within a river system.

Table 6 Precipitation Hydrograph



The above hydrograph demonstrates a series of varied intensity rainfall events over the course of a decade. The data points are distributed across the graph, with several distinct spikes indicating episodes of significant rainfall. These spikes are interspersed with periods of low to no rainfall, which are made as flat lines in y-axis.

There does not appear to be a consistent annual pattern of rainfall intensity; rather, the precipitation levels fluctuate without a clear repetitive seasonal trend.

Some years show multiple high-intensity events, while others have fewer and less pronounced peaks. This could suggest that the region experiences irregular rainfall or that it is influenced by varying weather patterns year on year.

The data also do not indicate a progressive increase or decrease in overall rainfall intensity throughout the years, which might rule out a linear trend. Instead, the precipitation appears to be episodic, with some years experiencing more extreme weather events than others. This kind of data is crucial for understanding the hydrological characteristics of the region, as well as for managing water resources and preparing for flood events. These results act as an input data for our simulation model.

Land Cover: Land cover data provides information on the types of vegetation present, which can affect the soil's capacity to absorb water. Different plants and trees have varying root depths and soil enhancement capabilities, which can significantly influence the soil's ability to retain water and thus affect flood dynamics.

The land coverage data was taken from sentinel 2 satellite imagery to understand the green blue infrastructure of the zimmensblock area. The data also does not indicate a progressive increase or decrease in overall rainfall intensity throughout the years, which might rule out a linear trend. Instead, the precipitation appears to be episodic, with some years experiencing more extreme weather events than others. This kind of data is crucial for understanding the hydrological characteristics of the region, as well as for managing water resources and preparing for flood events. These results act as an input data for our simulation model.

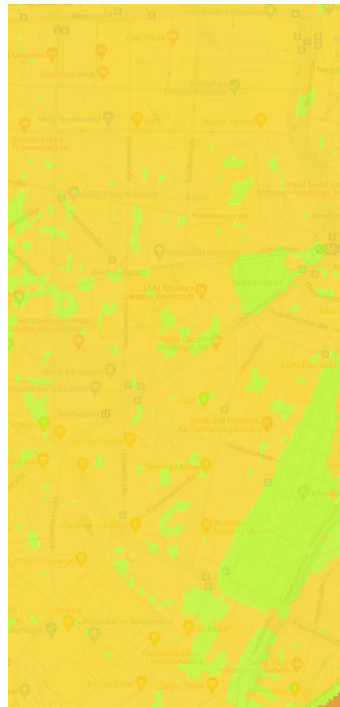


Figure 22 Sentinel 2 imagery on Land Cover

The structure of the land cover can alter the paths that water takes across the landscape. Bushes, for example, can intercept rainwater, while urban canyons created by building can channelize and accelerate the flow of water. The above land cover imagery shows the land cover area showing majorly streets in yellow, vegetation in green and water in orange.

Here in the context of flood simulation the Manning coefficient, often denoted as n , is an important parameter in hydraulic engineering used to estimate the roughness of a surface which water is flowing over (Takata, 2024). It's a factor in the Manning's equation, which is employed to calculate the flow velocity in open channels based on the channel's shape, slope, and roughness. Different land cover types have different surface roughness values. For example, a smooth concrete surface has a lower Manning coefficient because it offers less resistance to flow compared to a rough forest floor with dense under brush.

So, based on the land cover the different manning coefficients were taken accordingly:

1-forest	0,12
2-shrubs	0,1
3-grass	0,03
4-crops	0,05
5-building	0,02
6-bare	0,01

Figure 23 Manning's coefficient with respect to land cover

Infiltration: Infiltration is the process by which water on the ground surface enters the soil. When rainfall occurs, the ability of the soil to infiltrate water can greatly reduce the volume of water that becomes surface runoff, the infiltration capacity of the soil changes based on its saturation level, the dry soil can absorb water however when it's get saturated the ability of infiltration decreases which leads to surface runoffs. Urban areas with impervious surfaces, such as roads and buildings, have low infiltration rates because of the permissibility, leading to higher and faster runoff into drainage systems as seen in our case we don't have much vegetation in our area on interest.

The geology of Munich says most of it is covered by temperate brown and deep brown soils. The soil type is a shallow and nutrient-poor harvestation soil with high water permeability and low filtration capacity. For our simulation, we have used the SoilGrid data of Munich to download the infiltration zones (Bauer et al., 2005).

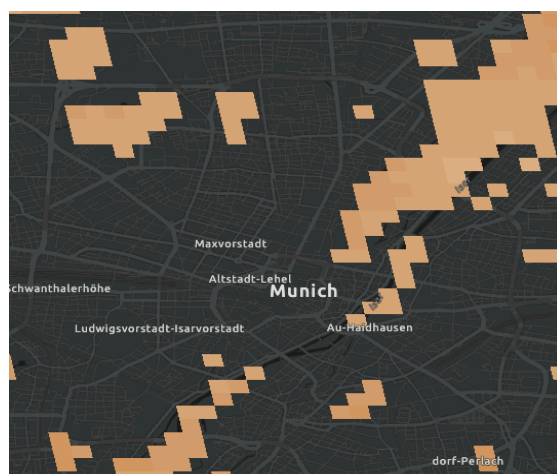


Figure 24 Munich clay content map from SoilGrid

Along with the infiltration two additional data were also provided which included :

- Effective soil moisture : 0.5
- Average soil depth : 5 cm.

All this data were derived from soilGrid opensource data sources which were further used in flood analysis.

Rainfall Prediction Model :

Machine learning is essential in rainfall prediction models due to its ability to process complex and varied data sets, such as temperature, humidity, and wind patterns, more efficiently than traditional methods. For our case we had data from the past for Munich which we used as a training data.

It significantly improves predictive accuracy, particularly with the use of advanced machine learning techniques. These models are capable of real-time analysis, which is crucial for timely and effective weather forecasting. From the predicted rainfall data we use this predicted data to make assumption on future flood scenarios and generate flood models out of it. (Liyew & Melese, 2021) We have chosen random forest algorithm for our prediction which belongs to the family of ensemble learning methods, Random Forest consists of a large number of individual decision trees that operate as an ensemble. Each individual tree in the Random Forest spits out a class prediction or a continuous output (depending on whether it's used for classification or regression), and the class with the most votes becomes the model's prediction (Meenal et al., 2021).

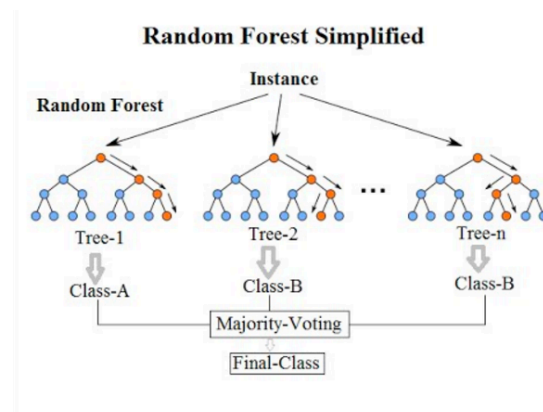


Figure 25 Simplified Random Forest algorithm (Koehrsen, 2020)

For our case in predicting flood scenarios the key strength of Random Forest is its robustness against overfitting, especially when dealing with large datasets. This is crucial in weather forecasting where the model needs to generalize well to unseen data. In addition, Random Forest algorithm can handle missing values in the data, which is a common issue in meteorological datasets, however in our case we didn't have much missing rainfall data.

Implementation of Random Forest Model:

First step involved was to clean and make the data ready for training, the data used was from the water department that consists of the rainfall data from 2013 to 2021, the data is summarised below:

Table 7 Mean Annual Rainfall data.

	Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	mean
0	Jan	72.2	19.8	73.3	74.9	34.6	4.0	0.0	18.6	48.4	38.422222
1	Feb	78.7	14.3	10.9	62.5	31.0	31.5	0.0	99.8	38.0	40.744444
2	Mar	44.2	22.8	43.7	41.3	36.2	25.0	3.7	37.9	37.3	32.455556
3	Apr	31.5	40.4	50.6	48.4	87.5	18.5	9.3	27.4	34.6	38.688889
4	May	137.2	77.5	139.5	103.8	79.7	105.9	126.2	46.6	118.7	103.900000
5	Jun	150.0	48.0	137.5	95.7	61.8	128.7	108.1	148.5	116.3	110.511111
6	Jul	38.5	113.3	50.6	94.8	113.6	113.3	67.6	100.6	136.7	92.111111
7	Aug	85.0	142.6	49.5	90.8	124.9	73.0	0.0	153.9	140.0	95.522222
8	Sep	82.6	79.6	47.7	61.4	61.9	102.9	11.2	59.0	36.0	60.255556
9	Oct	80.4	81.4	57.6	45.1	47.0	10.4	57.4	82.1	15.4	52.977778
10	Nov	53.8	34.7	59.6	57.1	59.5	0.7	26.7	19.9	33.4	38.377778
11	Dec	8.1	49.4	20.8	3.9	46.4	0.0	39.0	28.5	60.3	28.488889
12	Annual	862.2	723.8	741.3	779.7	784.1	613.9	449.2	822.8	815.1	732.455556

Input for the Random Forest Algorithm:

Dataset: The input dataset is loaded from an Excel file named "Traingrain.xlsx" using pandas. This dataset contains historical rainfall data, including year, month, and average rainfall collected from the water department.

Features (X): The features used to train the Random Forest model are extracted from the dataset columns 'Year' and 'Month', which are then converted to a numpy

array and cast to integers. These features represent the time information of the rainfall data.

Shape of X: It represents the number of samples and the number of features used for training. Based on the code, **X.shape** would output the shape of this array.

Target (y): The target variable is the 'Avg_Rainfall' column from the dataset, which is also converted to a numpy array and cast to integers. This column represents the amount of rainfall, which the model will learn to predict.

Shape of y: It indicates the number of target values corresponding to the input features. The shape is outputted to confirm the data's structure before training.

- **Training and Testing Split:** The dataset is split into training and testing sets, with 70% used for training and 30% for testing. This is done using the **train_test_split** method from scikit-learn, ensuring that the model can be evaluated on unseen data.
- **Model Parameters:** Specific parameters for the Random Forest Regressor are defined, including **max_depth**, **max_features**, **min_samples_leaf**, **min_samples_split**, and **n_estimators**. These parameters configure how the Random Forest algorithm will be trained.

Output of the Random Forest Algorithm:

- **Model Training:** The Random Forest model is trained on the training data (**X_train, y_train**) using the specified parameter
- **Predictions:** The trained model makes predictions on both the training set (**y_train_predict**) and the testing set (**y_test_predict**), allowing for the evaluation of model performance.
- **Accuracy Scores:** The model's accuracy on both the training and testing sets is calculated and printed. These scores indicate how well the model has learned from the training data and its performance on unseen data, respectively.

Model Creation and Training:

The Random Forest Regressor is chosen for its ability to handle complex datasets with non-linear relationships, which is common in weather data. The training process involves the model learning to associate the input features (like temperature, humidity) with the target variable (rainfall). The specific parameters set for the model define how it learns, preventing issues like overfitting and underfitting to ensure a good balance between bias and variance.

```
RandomForestRegressor
RandomForestRegressor(max_depth=100, max_features='sqrt', min_samples_leaf=4,
                       min_samples_split=10, n_estimators=800)
```

A `RandomForestRegressor` from `sklearn.ensemble` is instantiated with specific parameters like `max_depth`, `max_features`, `min_samples_leaf`, `min_samples_split`, and `n_estimators`.

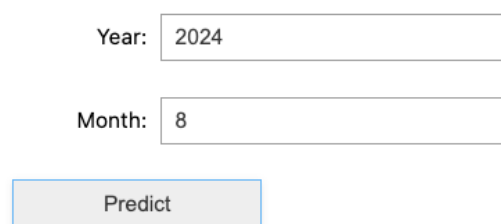
The model is then trained using `fit` on the training dataset (`X_train`, `y_train`).

Prediction and Evaluation: The trained model is used to predict rainfall for both training (`y_train_predict`) and testing datasets (`y_test_predict`). Evaluation metrics (Mean Absolute Error - MAE, Mean Squared Error - MSE, Root Mean Squared Error - RMSE) are calculated for both sets to assess the model's performance.

Both the training and testing datasets are used to evaluate the model's rainfall prediction capability after it has been trained. This assessment is essential to determine the correctness and generalization of the model. The selected metrics (MAE, MSE, RMSE) aid in assessing the model's performance overall by offering insights into various areas of the prediction errors.

Single Prediction: Making a prediction for a specific year and month demonstrates the practical application of the model. It's a way to see how the model works in a real-world scenario, providing a single, specific prediction based on the learned patterns.

Interactive Prediction Setup: Interactive widgets (IntText for year and month, Button for prediction) are created using ipywidgets. A function `predict_data` is defined to make predictions based on the input from these widgets. `predict_button.on_click(predict_data)` binds the prediction function to the button click event. This part of the code creates a user interface for making predictions. It allows users to input new data (year and month) and receive predictions without delving into the code. This interactivity makes the model more accessible and user-friendly, particularly for users who may not be familiar with Python or machine learning



Year:

Month:

3.4 Visualization

In all the previous steps it is explained the procedure to collect, improve the data and integrate it for the purpose of analysis and simulation. Now, we understand the representation of all these data altogether.

3.4.1 Weather API integration

We have enhanced our model by incorporating data from a weather API, which provides historical records of the most severe rainfall events for any given month. This integration significantly refines the accuracy of our flood simulations and management strategies and also provides a nice user experience.

The utilization of such precise meteorological data is essential for predicting the probability and intensity of potential flood scenarios across different locales. This level of detail is indispensable for emergency services and municipal authorities when orchestrating preparations for extreme weather conditions.

Employing this data enables the strategic deployment of resources, the orchestration of preventive evacuations, and the establishment of robust flood defenses. Moreover, this

meteorological information is extremely valuable for the strategic planning and development of infrastructure. It equips engineers and urban planners with the insights needed to design and fortify structures—such as water drainage systems, dams, and levees—to endure significant rainfall events, thereby enhancing their resilience against severe weather.

However, in this paper the flood simulation is solely based on flood prediction on precipitation hydrographs from the historical rainfall data and statistical analysis, however it this API which could help us to know live data for enhanced user experience and as scope for future improvement of the simulation model.

For this paper we have used the weather API that we used for fetching weather condition, temperature, rain probability, rain amount.

Table 8 API service listings of weather API

Realtime API

Current weather or realtime weather API method allows a user to get up to date current weather information in json and xml. The data is returned as a Current Object.

Current object contains current or realtime weather information for a given city.

Field	Data Type	Description
last_updated	string	Local time when the real time data was updated.
last_updated_epoch	int	Local time when the real time data was updated in unix time.
temp_c	decimal	Temperature in celsius
temp_f	decimal	Temperature in fahrenheit
feelslike_c	decimal	Feels like temperature in celsius
feelslike_f	decimal	Feels like temperature in fahrenheit
condition:text	string	Weather condition text
condition:icon	string	Weather icon url
condition:code	int	Weather condition unique code.
wind_mph	decimal	Wind speed in miles per hour
wind_kph	decimal	Wind speed in kilometer per hour

Additionally, the model also checks the worst rainfall pattern and intensity over the present month which might be helpful in future scope of the project.

```

async function getWorstRainfallThisMonth(apiKey) {
  const today = new Date();
  const firstDayOfMonth = new Date(today.getFullYear(), today.getMonth(), 1);
  const lastDayOfMonth = new Date(today.getFullYear(), today.getMonth() + 1, 0);
  let worstRainfall = 0;
  let worstDay = null;

  for (let day = firstDayOfMonth; day <= lastDayOfMonth; day.setDate(day.getDate() + 1)) {
    const dateString = day.toISOString().split('T')[0];
    const weatherApiUrl = `https://api.weatherapi.com/v1/history.json?key=${apiKey}&q=Munich&dt=
    // Fetch data for each day and parse it
    const response = await fetch(weatherApiUrl);
    const data = await response.json();
    const dailyRainfall = data.forecast.forecastday[0].day.totalprecip_mm;

    if (dailyRainfall > worstRainfall) {
      worstRainfall = dailyRainfall;
      worstDay = dateString;
    }
  }

  return { worstRainfall, worstDay };
}

```

Munich Weather:
Condition: Overcast
Temperature: -6 °C
Rain Probability: 0%
Rain Amount: 0 mm

The picture above represents what we fetch and show in our web application. This is one of the live data fetched in 12th Jan 2024.

3.4.2 Web application

The web application was made for the reason for visualisation, the objective was to have a quick visualisation that could load all the semantics including all the IFC models and other models from the city GML as discussed above in a simple and user-friendly way. After the successful import of the model, we proceed with the simulation showing the flood level within our area of interest.

The methods involved in building the web application is explained below:

Mapbox as a rastertile : Mapbox is a popular location data platform for mobile and web applications. It provides developers with powerful tools to create custom, dynamic maps and location-based experiences. Utilizing a combination of satellite imagery, vector tiles, and a robust set of APIs, Mapbox enables the integration of detailed, interactive maps into applications. Its usage here is for the purpose of a raster tile upon where we build our model on.

Model Import : Model X, a comprehensive and versatile model, is specifically designed for advanced urban and environmental simulations. The key aspect of Model X is its ability to bridge the gap between detailed architectural models and geospatial data, enabling a more realistic and accurate representation of urban environments inside our visualisation.

Alongside IFCs, Model X incorporates CityGML data. CityGML is an open standardized data model and exchange format that defines the geometry, topology, and semantics of 3D city models. Elevation data is another crucial component of Model. All the procedure of the integration are explained in the previous part of the paper. So, once the IFCs, CityGML, and elevation data are compiled, they are converted into an FBX file format. FBX (Filmbox) is a popular format known for its versatility in handling both 2D and 3D data. This conversion is a crucial step as it makes the data compatible with a wide range of 3D modelling software, including Blender. Blender is an open-source 3D creation suite, widely used for its powerful modelling, texturing, and animation tools. The transformation of Model X into an FBX file opens numerous possibilities. It allows for further enhancements and manipulations in Blender or similar software, where additional details, textures, and animations can be added to the model.

This enhanced model can then be exported for use in various applications, including web-based platforms for example gltf formats which is well renowned and used in web applications due to its light weight and support with WebGL. In web applications, Model X is used for a variety of purposes, for simulations.

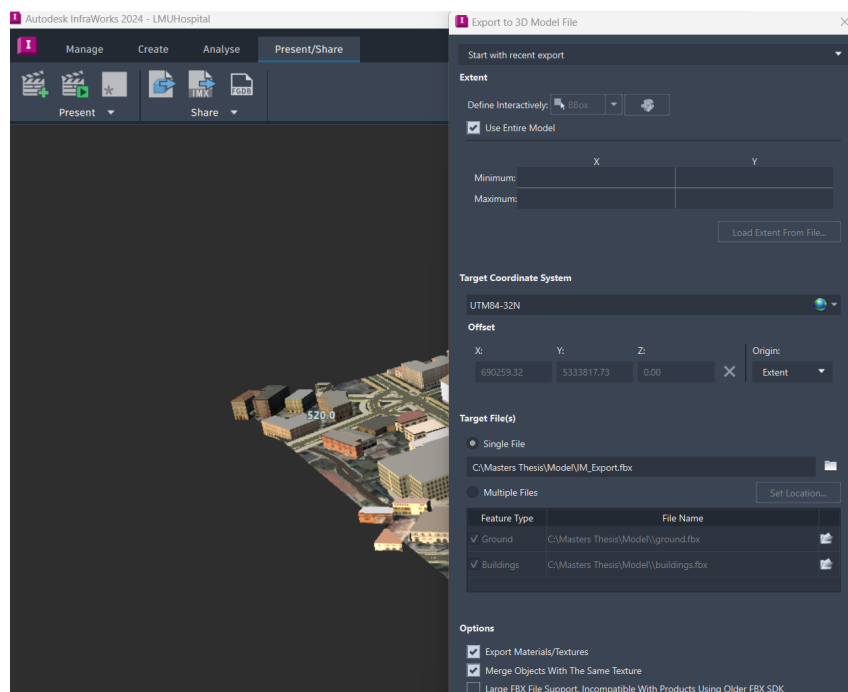


Figure 26 Picture of Infracworks FBX export window

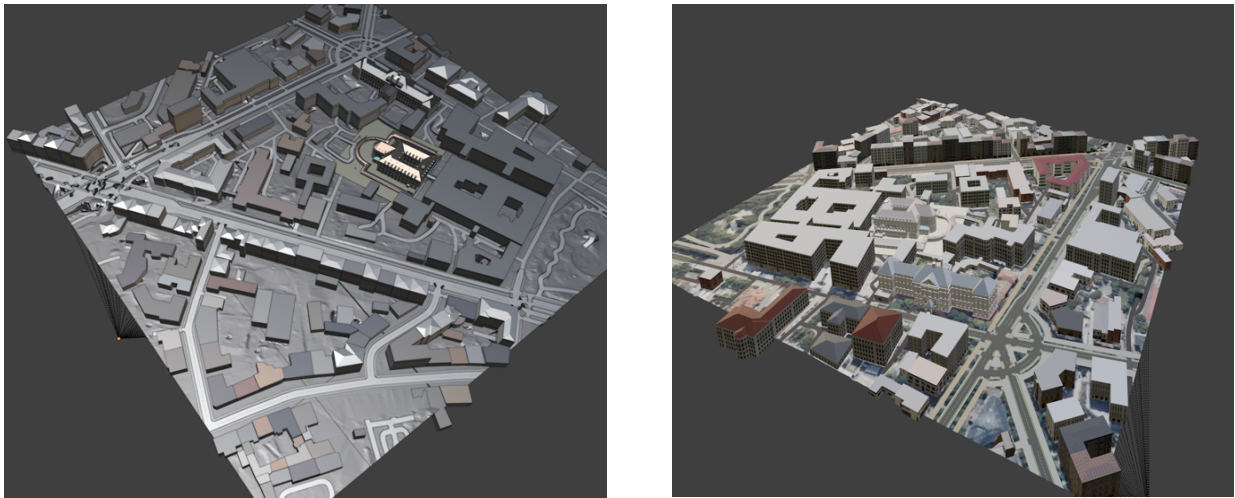
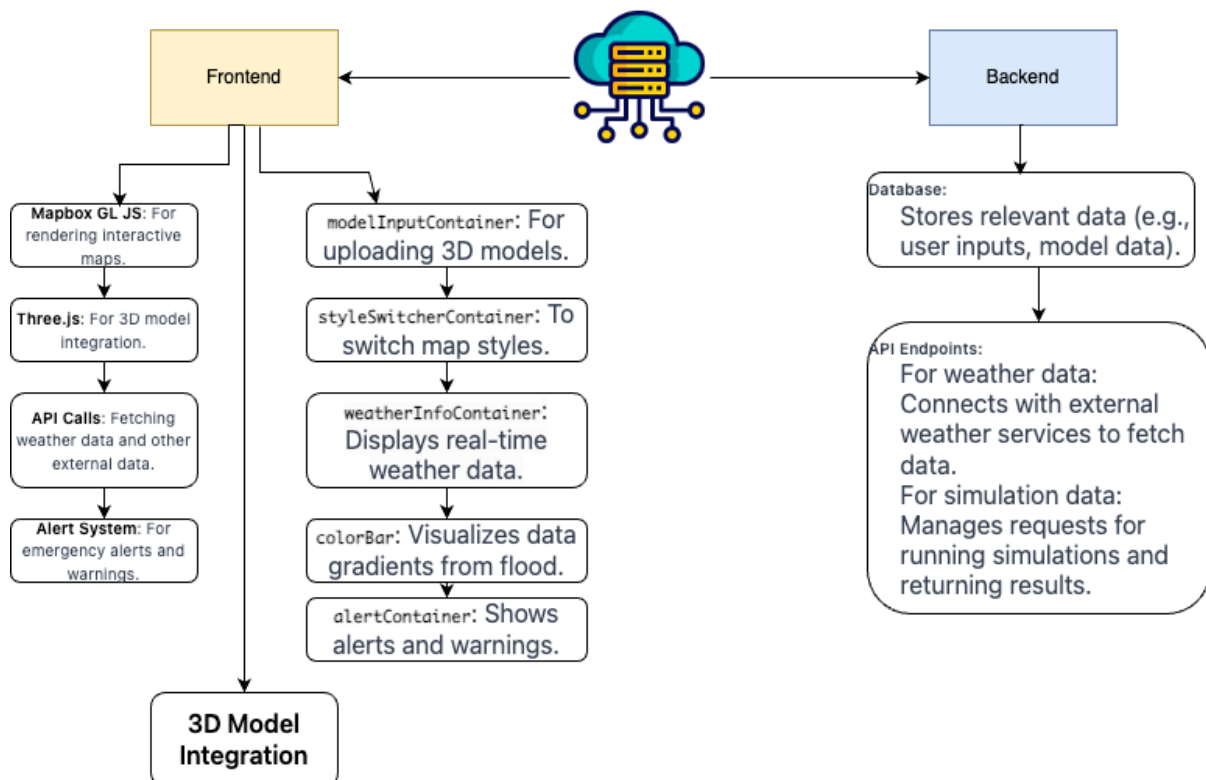


Figure 27 Picture of Model X in blender

Web framework :

Table 9 Web application Architecture



The web application developed for flood simulation represents an intricate and well-orchestrated integration of multiple web technologies, primarily focusing on HTML, CSS,

and JavaScript,(the basic framework used for the web application) while leveraging the capabilities of Mapbox GL JS and Three.js for enhanced geographical and 3D visualizations, which supports georeferenced models.

HTML Structure: The HTML layout used in this paper serves as the structural foundation. It segments the web page into distinct sections, each with a dedicated purpose. The `modellInputContainer` allows for the importation of 3D models, crucial for simulating the flood in a realistic environment. The `styleSwitcherContainer` offers the functionality to switch between different map styles, like 'Satellite Streets' and 'Standard', providing flexibility in visual presentation. The `weatherInfoContainer` dynamically displays weather information, crucial for understanding the environmental conditions influencing the flood simulation. Additional elements like the `colorBar` enhance the data visualization aspect providing a gradient bar for an intuitive understanding of data metrics like water depth or intensity relevant to the simulation.

CSS Styling: The CSS styling ensures that the application is not only functional but also visually appealing and user-friendly. Elements like the `alertContainer` are styled to have alert functionality in case of emergency, which would be explained in detailed in the feature section in the later parts. The use of absolute positioning and z-index ensures that critical information overlays the map correctly and is easily accessible. The responsive design of the map container (`#map`) ensures that the application is adaptable to different screen sizes, enhancing user experience.

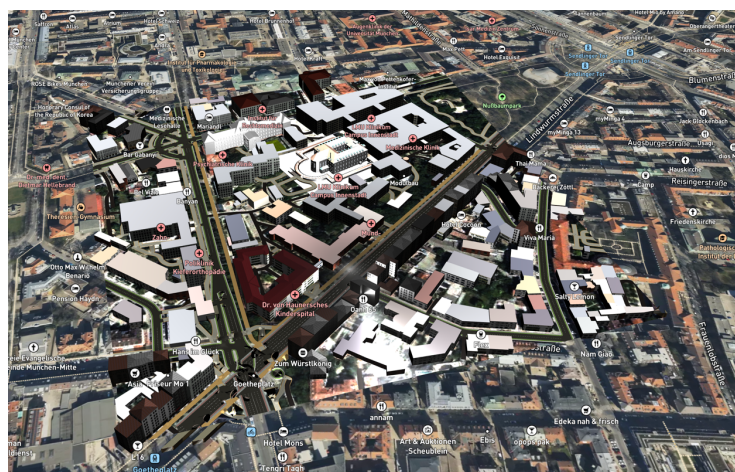


Figure 28 Model X in the web application

JavaScript Functionality: JavaScript is at the core of our application's interactivity and functionality. Which consists the logic behind. It initializes the Mapbox map, a critical component for rendering geographical data. The integration of the Mapbox GL JS library enables the depiction of high-resolution maps, which are essential for accurately simulating flood scenarios. The application also takes advantage of Three.js, a JavaScript library that renders 3D models.

This is evident in the functionality provided to upload and display 3D models within the map which include the entire model X consisting IFCs, City GML etc, allowing for a more immersive simulation experience.

The script further enhances the application's functionality by incorporating external weather data through API calls. This feature not only fetches current weather conditions but also calculates and displays the worst rainfall data for the month, adding a layer of depth to the simulation by providing historical context. The implementation of an alert system, complete with visual and alarms, is a testament to the application's attention to detail. This system is designed to simulate real-world emergency alerts, enhancing the realism of the flood scenario.

Interaction Between Frontend and Backend:

The frontend sends requests to the backend (e.g., for weather data).

The backend processes these requests, interacts with the database or external APIs as needed, and sends back the required data or results.

The frontend then uses this data to update the map, display weather information, render 3D models, or trigger alerts.

Data Flow:

User Interaction: Users interact with the frontend elements, triggering events.

Request Handling: JavaScript captures these events and sends requests to the backend.

Data Processing: The backend processes these requests, accessing the database or external APIs.

Response: The backend sends back the processed data or results to the frontend.

Update UI: The frontend updates the user interface based on the received data, such as updating the map, displaying weather info, or showing 3D models.

Alerts and Notifications: The alert system in the frontend gets activated based on specific conditions or backend responses.

Integration of flood data :

The integration of flood data into our web application involves a meticulous process utilizing Python's robust libraries—Numpy for numerical computations, Matplotlib for data visualization, and Rasterio for handling geospatial raster data. Initially, we employ Rasterio to open a GeoTIFF file, 'flood.tiff', which contains the flood simulation data from our flood simulation software where we extract the flood data as a TIFF file. This file format is ideal for storing raster graphics and is commonly used in geographic information systems for its capability to embed georeferencing information. Upon accessing the file, we extract the elevation data using Rasterio. Elevation is a critical component in flood modeling as it influences how water flows and accumulates in different areas. We then create a meshgrid using Numpy, which provides X and Y coordinates corresponding to the longitude and latitude of the dataset. This meshgrid is essential for plotting the elevation data in a two-dimensional space.

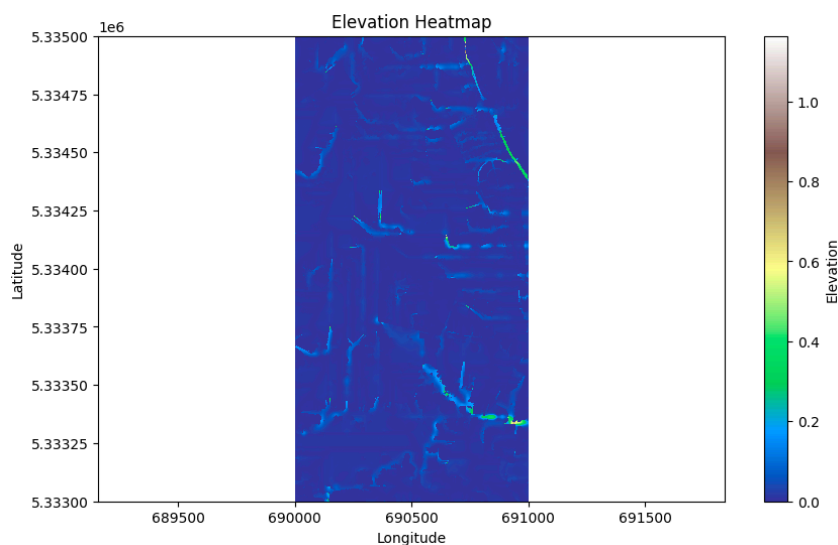


Figure 29 Rainfall data with elevation

With the help of Matplotlib, a powerful plotting library, we visualize this data. We generate a heatmap using the `pcolormesh` function, effectively displaying the elevation data. The color map 'terrain' is chosen to represent different elevation levels visually, making the data more accessible and understandable.

A color bar is added as a legend to relate colors to elevation values, as shown in the above image. In a refined approach for a specific flood scenario, we further process the elevation data by setting values of 0.05.

This step helps in emphasizing areas with significant flooding, enhancing the visualization's accuracy and relevance to the flood simulation.

Finally, these visualizations are not just static images; they are translated into raster tiles and superimposed onto the Mapbox map within the web application. This integration provides users with an interactive and detailed view of potential flood impacts in the context of real-world geography. Alongside this, Model X, which includes detailed urban and architectural data, is also integrated, offering a comprehensive and multidimensional perspective of flood scenarios in urban settings.

This method of flood data integration highlights the application's capability to combine scientific data processing with sophisticated web mapping technologies, delivering a powerful tool for visualizing, and understanding flood impacts.

Web features : All the features available in the model are explained below :

Interactive Map and ID Model Loading: The '#modellInputContainer' allows users to upload 3D models (.glTF or .glb files) for visualization on the map. This interactivity adds a layer of customization, enabling users to see their own models in the context of the flood simulation. This is what we call the model X. This actually opens up news scope of the project in future when we try to integrate any other model in our map.

The modellInput.addListener function listens for changes in the model input field and triggers the loading of the 3D model onto the map.

Map Style Switcher: The '#styleSwitcherContainer' contains a dropdown (#styleSwitcher) that lets users switch between different map styles, such as 'Satellite Streets' and

'Standard'. This feature enhances user interaction by allowing them to choose their preferred map visualization.

Dynamic Weather Information Display:The '#weatherInfoContainer' is used to display real-time weather information. This feature is particularly valuable in the context of a flood simulation application, as it provides users with relevant environmental data.

Color Bar for Data Visualization:A color bar ('#colorBar') is included to provide a visual guide to interpret data gradients, such as elevation levels or water depths for our flood. This feature aids in understanding the simulation data more intuitively.

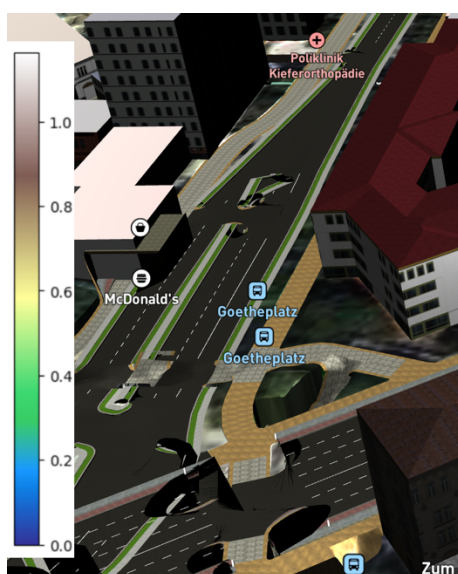


Figure 30 Flood elevation bar as in web application

Interactive Alert System:The '#alertContainer' is a crucial UI element designed to display emergency alerts. It becomes visible when certain conditions are met in the simulation, such as reaching critical flood levels. It shows the user where exactly in the models are at risk.

The showAlert function, along with an audio alert ('#alertSound'), is set to trigger after a specific timeout, drawing users' attention to urgent situations.



Figure 31 Picture of alerts in vulnerable areas

Interactive Map Features: Clickable elements on the map are enhanced with popups. For example, clicking on the 'room-extrusion' layer triggers a popup that displays detailed information about the clicked area, like building name (which includes the type of import either its an IFC or its a LoD2 building of cityGML), flood level, and status.

The application changes the cursor style when hovering over interactive map elements (`map.on('mouseenter', 'room-extrusion', function() {...})`), improving user experience by indicating clickable areas.

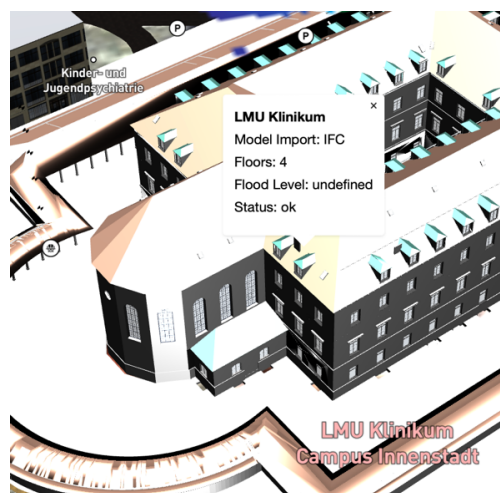


Figure 32 Clickable features inside web application

Custom Layer for 3D Models: The custom Layer configuration and its integration with the Three.js library enables the realistic rendering of 3D models on the map. This layer is dynamically rendered and responds to map movements and style changes.

Responsive UI Design:

The application's UI elements are styled with CSS for a clean, uncluttered look and are positioned fixedly over the map, ensuring they are always accessible regardless of scrolling or map navigation.

3.4.3 Setting Up Game Engine with Unreal Engines

Unreal Engine 5 emerges as a groundbreaking tool in the realm of visualization, particularly for simulations that demand high-fidelity and immersive experiences. Renowned for its advanced graphics capabilities and real-time rendering power, Unreal Engine 5 enables the creation of incredibly realistic and detailed environments (*Unreal Engine Is an Advanced Training and Simulation Software Platform, 2023*).

This makes it an ideal platform for conducting various types of simulations, ranging from architectural visualizations to complex environmental scenarios like flood simulations. Its ability to handle intricate lighting, physics, and material properties allows for a level of realism that is pivotal in accurately modeling and understanding real-world phenomena. Furthermore, Unreal Engine 5's robust suite of tools, including its revolutionary Nanite virtualized geometry and Lumen global illumination technologies, empowers developers to craft rich, interactive 3D scenes with unprecedented ease and precision. In the context of simulations, this means being able to recreate scenarios with a high degree of accuracy and interactivity, providing valuable insights into how different factors interact in dynamic environments. We use this game engine for the flood simulation which consists of better and high end graphics which we would miss in our web application.

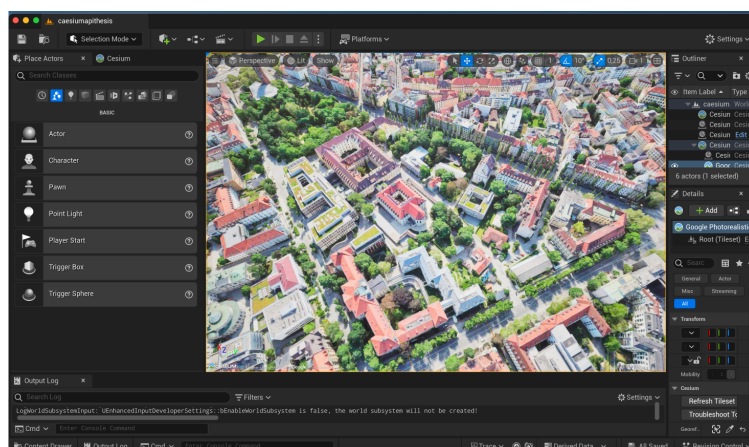


Figure 33 Zimmensblock on unreal engines

The steps involved in the simulation are explained below :

- *Acquiring Google Earth Imagery:* Google Earth provides high-resolution satellite imagery which is beneficial for creating a realistic base layer for our simulation.
- We choose and select our area of interest and fix our center coordinates and corresponding zoom levels. We also had to acquire the google cloud api in order to use google earth inside unreal engines.
- *Utilize Cesium for 3D Visualization:* Importing the Google Earth imagery into Cesium, a platform known for its capability to render accurate 3D global imagery. Cesium helps in creating a detailed and interactive 3D scene of your chosen area. Cesium can be found as a plug in to the unreal engine. We need to replace the source of the cesium tile map into google tile map in order to use google earth feature inside. We adjust the LoD according to our graphics and computation power of the pc.
- *Prepare the Flood Data:* We ensure that the TIFF file, which holds the flood level data, is in the correct format and contains all the necessary geospatial information. This file should represent various flood levels across the area of interest.
- *Conversion for Compatibility:* If necessary, convert the 'flood.tiff' file into a format that is compatible with Cesium. Cesium generally supports a range of geospatial data formats, but ensuring compatibility is crucial for seamless integration.
- *Importing into Cesium:* Import the 'flood.tiff' file into your Cesium project. This can typically be done through Cesium's data import tools or APIs, which allow for the integration of custom geospatial data.
- *Overlaying Flood Data:* Overlay the flood level data from the 'flood.tiff' file onto the Google Earth imagery within Cesium. This step is critical as it combines the realistic base imagery with the specific flood simulation data.

3.4.4 Sewage Network

Stormwater drains are part of the sewage system, which is intended to divert water away from populated areas. Understanding these systems' capacities and flow pathways is crucial to flood modeling because it helps forecast how water will travel across a region during periods of high rainfall or flooding. A restricted capacity of the sewage system may cause water to back up and exacerbate flooding. Flood models need to account for these artificial drainage paths to accurately simulate urban hydrology under flood conditions. During extreme weather events, sewage systems can become overwhelmed and overflow. This can lead to additional flooding, particularly in low-lying areas. Accurately modeling the capacity and potential overflow points of sewage systems helps in predicting areas at risk of inundation (Yang et al., 2020).

In my thesis, we employed the Storm Water Management Model (SWMM), an advanced computational tool developed by the Environmental Protection Agency, to analyze and simulate urban drainage systems and surface runoff in zimmensblock area. The primary aim was to assess the effectiveness of existing stormwater infrastructure under various rainfall scenarios and to propose enhancements for flood mitigation. Utilizing SWMM's dynamic hydrology-hydraulic modeling capabilities, we meticulously configured the model to replicate the local urban catchment, incorporating detailed data on land use, soil characteristics, and existing drainage networks. We have used the KOSTRA statistical data for the rainfall intensity. The outcomes of this research were significant; the model not only demonstrated the current limitations and vulnerabilities of the existing stormwater system under extreme weather conditions explained below (Son et al., 2016). We begin with setting up the piping network in the swmm using a raster tile of the Zimmensblock area collected from stBA Munich, who provided us CAD models consisting every information on sewage network on that area.

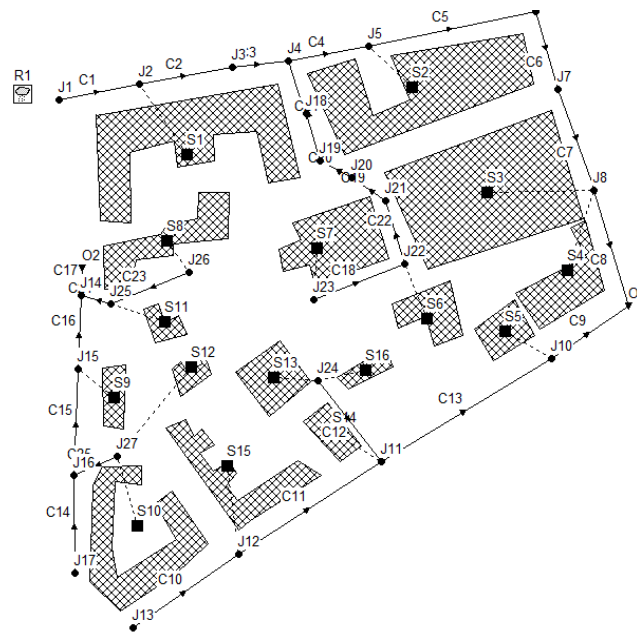


Figure 34 Pipe Network simplified of LBD from StBA München

The next step include getting the subcatchment areas shown in the above picture as hatched line and also marked by S1 to S16, now we plot the junction node accordingly the elevation of the nodes were provided by the StBA as mentioned above.

The junction are marked as J1 to J27 in the above picture. Each of the junctions are connected by conduits labeled from C1 to C25. The shape of the conduits which are circular are designed and also the depth of 1.5 m are assigned to each conduit. The next steps involves setting the rain gauge as per the KOSTRA statistical 10 year return period data.

The last step is to set the outlets , we consider two outlets for our entire area. The assumption is made based on the direction of the flow and the junction with the main sewage pipes.

Results :

The summary of the results are shown in the charts below :

Table 10 Chart showing sub catchment runoff.

Subcatchment	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Imperv Runoff mm	Perv Runoff mm	Total Runoff mm	Total Runoff 10 ^{^6} ltr	Peak Runoff CMS	Runoff Coeff
S1	158.20	0.00	0.00	2.72	39.59	112.81	152.40	7.62	0.68	0.963
S2	158.20	0.00	0.00	2.72	39.59	112.81	152.40	7.62	0.68	0.963
S3	158.20	0.00	0.00	2.72	39.59	112.81	152.40	7.62	0.68	0.963
S4	158.20	0.00	0.00	2.72	39.59	112.81	152.40	7.62	0.68	0.963
S5	158.20	0.00	0.00	2.72	39.59	112.81	152.40	7.62	0.68	0.963
S6	158.20	0.00	0.00	2.72	39.59	112.81	152.40	7.62	0.68	0.963
S7	158.20	0.00	0.00	2.72	39.59	112.81	152.40	7.62	0.68	0.963
S8	158.20	0.00	0.00	2.72	39.59	112.81	152.40	7.62	0.68	0.963
S9	158.20	0.00	0.00	2.72	39.59	112.81	152.40	7.62	0.68	0.963
S10	158.20	0.00	0.00	2.72	39.59	112.81	152.40	7.62	0.68	0.963
S11	158.20	0.00	0.00	2.72	39.59	112.81	152.40	7.62	0.68	0.963
S12	158.20	0.00	0.00	2.72	39.59	112.81	152.40	7.62	0.68	0.963
S13	158.20	0.00	0.00	2.72	39.59	112.81	152.40	7.62	0.68	0.963
S14	158.20	0.00	0.00	2.72	39.59	112.81	152.40	7.62	0.68	0.963
S15	158.20	0.00	0.00	2.72	39.59	112.81	152.40	7.62	0.68	0.963
S16	158.20	0.00	0.00	2.72	39.59	112.81	152.40	7.62	0.68	0.963

Table 11 Chart for Node flooding

Node	Hours Flooded	Maximum Rate CMS	Day of Maximum Flooding	Hour of Maximum Flooding	Total Flood Volume 10 ^{^6} ltr	Maximum Poned Volume 1000 m3
J3	5.14	0.629	0	05:03	5.918	0.000
J4	5.00	0.479	0	05:38	7.433	0.000
J5	5.55	0.675	0	05:00	7.248	0.000
J15	3.21	0.992	0	05:00	6.052	0.000
J22	4.07	0.890	0	05:00	7.112	0.000
J26	5.21	0.595	0	05:00	5.961	0.000

Table 12 Chart showing node depth.

Node	Type	Average Depth Meters	Maximum Depth Meters	Maximum HGL Meters	Day of Maximum Depth	Hour of Maximum Depth	Maximum Reported Depth Meters
J1	JUNCTION	0.00	0.00	17.00	0	00:00	0.00
J2	JUNCTION	0.51	0.77	17.02	0	05:00	0.77
J3	JUNCTION	1.38	1.50	17.67	0	00:41	1.50
J4	JUNCTION	1.28	1.50	17.67	0	01:00	1.50
J5	JUNCTION	1.45	1.50	17.67	0	00:27	1.50
J6	JUNCTION	1.23	1.50	17.67	0	01:33	1.50
J7	JUNCTION	0.92	1.23	17.39	0	06:00	1.23
J8	JUNCTION	0.78	1.18	17.34	0	06:00	1.18
J10	JUNCTION	0.55	0.84	19.01	0	05:02	0.84
J11	JUNCTION	0.55	0.84	19.96	0	05:00	0.84
J12	JUNCTION	0.22	0.32	21.56	0	05:00	0.32
J13	JUNCTION	0.00	0.00	21.27	0	00:00	0.00
J14	JUNCTION	1.09	1.50	22.50	0	02:35	1.50
J15	JUNCTION	1.12	1.50	22.55	0	02:05	1.50
J16	JUNCTION	0.71	1.19	22.35	0	05:02	1.14
J17	JUNCTION	0.00	0.00	21.16	0	00:00	0.00
J18	JUNCTION	0.00	0.00	16.87	0	00:00	0.00
J19	JUNCTION	0.52	0.66	17.61	0	05:34	0.64
J20	JUNCTION	0.53	0.67	17.69	0	01:44	0.66
J21	JUNCTION	1.19	1.50	19.04	0	01:44	1.50
J22	JUNCTION	1.23	1.50	19.05	0	01:12	1.50
J23	JUNCTION	0.25	0.37	19.14	0	05:00	0.37
J24	JUNCTION	0.33	0.48	21.37	0	05:00	0.48
J25	JUNCTION	1.25	1.50	22.55	0	01:35	1.50
J26	JUNCTION	1.42	1.50	22.55	0	00:27	1.50
J27	JUNCTION	0.72	1.14	22.40	0	05:00	1.14

Table 13 Chart for outfall loading

Outfall Node	Flow Freq. Pcnt.	Avg. Flow CMS	Max. Flow CMS	Total Volume 10 ⁶ ltr
O1	99.03	2.508	4.828	53.630
O2	96.11	1.213	1.822	25.168

Table 14 Chart for conduit surcharge

Conduit	Hours Both Ends Full	Hours Upstream Full	Hours Dnstream Full	Hours Above Normal Flow	Hours Capacity Limited
C3	5.13	5.13	5.13	4.34	5.13
C4	5.00	5.00	5.00	4.31	5.00
C5	5.55	5.55	5.55	4.55	5.55
C16	3.20	3.20	3.20	3.17	3.20
C22	4.06	4.06	4.06	3.96	4.06
C23	5.20	5.20	5.20	4.53	5.20

Table 15 Chart showing link flow.

Link	Type	Maximum [Flow] CMS	Day of Maximum Flow	Hour of Maximum Flow	Maximum [Velocity] m/sec	Max / Full Flow	Max / Full Depth
C1	CONDUIT	0.000	0	00:00	0.00	0.00	0.00
C2	CONDUIT	0.710	0	05:02	0.88	0.55	0.51
C3	CONDUIT	0.087	0	01:44	0.05	1.08	1.00
C4	CONDUIT	0.087	0	01:44	0.05	1.08	1.00
C5	CONDUIT	0.087	0	01:31	0.05	1.08	1.00
C6	CONDUIT	0.080	0	06:00	0.20	0.17	0.28
C7	CONDUIT	0.077	0	06:00	0.05	0.96	0.80
C8	CONDUIT	1.467	0	05:02	1.30	0.80	0.66
C9	CONDUIT	3.378	0	05:01	3.87	0.50	0.50
C10	CONDUIT	0.000	0	00:00	0.00	0.00	0.00
C11	CONDUIT	0.684	0	05:01	2.52	0.10	0.21
C12	CONDUIT	1.366	0	05:01	2.88	0.22	0.32
C13	CONDUIT	2.713	0	05:02	2.75	0.61	0.56
C14	CONDUIT	0.000	0	00:00	0.00	0.00	0.00
C15	CONDUIT	1.419	0	05:06	1.09	0.93	0.74
C16	CONDUIT	1.111	0	02:30	0.77	1.08	1.00
C17	CONDUIT	1.822	0	05:04	3.18	0.28	0.36
C18	CONDUIT	0.685	0	05:01	2.10	0.14	0.25
C19	CONDUIT	0.499	0	01:44	1.39	0.15	0.26
C20	CONDUIT	0.481	0	05:34	0.68	0.40	0.43
C21	CONDUIT	0.479	0	05:38	1.56	0.12	0.23

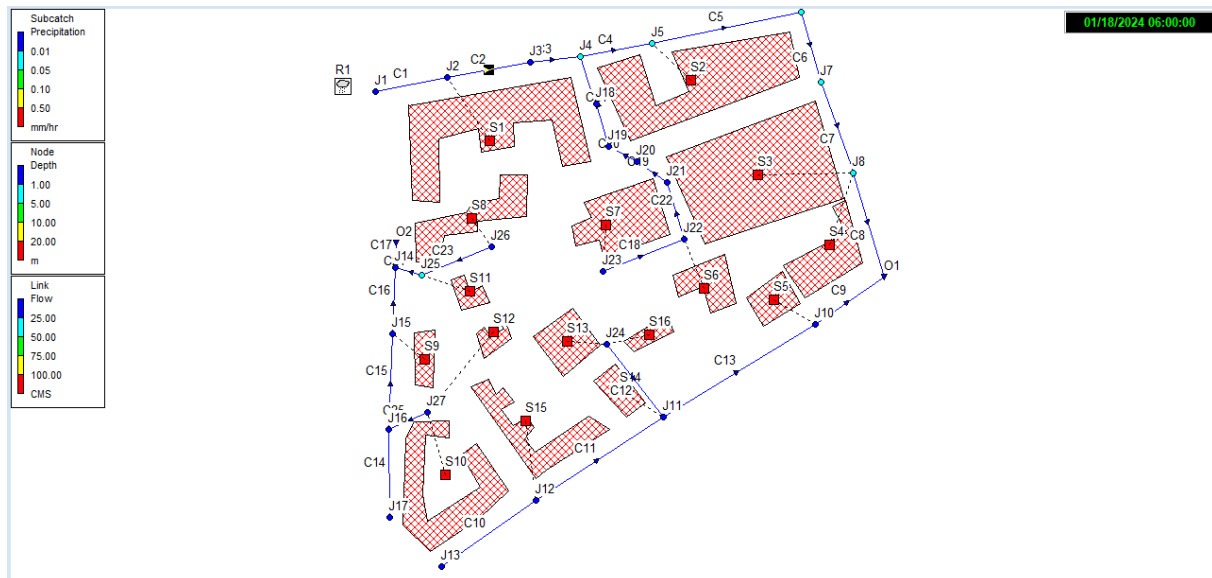


Figure 35 Results from SWMM

Map showing water depth, precipitation and flow at node, sub catchment and link respectively.

Summary :

Subcatchment Runoff:

- All subcatchments (S1 to S16) experienced the same total precipitation of 158.20 mm.
- There was no surface runoff (0.0 mm) and the total evaporation was also zero, suggesting either a very high infiltration rate, a simulation of a permeable surface.
- Each subcatchment had the same total infiltration (2.72 mm), impervious runoff (39.59 mm), pervious runoff (112.81 mm), and total runoff (152.40 mm), indicating uniform land use, soil type, and slope or an overly simplified model setup.
- The total runoff volume was 7.62×10^6 liters for each subcatchment.
- Peak runoff rate (CMS) and Runoff Coefficient were consistent across all subcatchments (0.68 CMS and 0.963, respectively).

Node Depth :

- Nodes J1 through J27, presumably, show a mixture of average and maximum depths, with a majority of nodes having some water depth, which indicates that they are part of active drainage system.
- The maximum Hydraulic Grade Line (HGL) meters, which reflect the water surface elevation, ranged from 17.00 to 22.55 meters across nodes, with the maximum HGL typically occurring at the same hour as the maximum depth reported.
- The day of maximum depth was zero for all nodes, again suggesting a simulation conducted over a short period or a single storm event.

Conduit Surge:

- Conduits C3, C4, and C5 experienced both ends full for 5.13, 5.00, and 5.55 hours, respectively, which is consistent with the hours of upstream and downstream full conditions.

- The hours above normal flow and hours capacity limited are slightly lower than the hours both ends full, indicating there may have been periods where the flow was high but did not completely surcharge the conduit.
- Conduit C16 shows the least stress with only 3.20 hours of both ends full and capacity limitation, while C5 shows the most with 5.55 hours.

Conclusion

The system demonstrates a high degree of uniformity in response to precipitation, which could suggest either an overly simplified model(which is done by simplifying the existing network and some assumptions), a highly consistent terrain and land use across the modeled area.

The node flooding data point to specific areas prone to flooding, with node J15 experiencing the highest flow rate, which could indicate a localized low point or bottleneck. Conduit surcharge information reveals that several conduits are operating at or near their full capacity, suggesting that certain segments of the drainage network may be undersized or facing blockage issues.

The outfall loading data reinforce the presence of a potentially overtaxed system, especially at outfall O1, which handles a significant volume of water.

4 Result

4.1 Simulation Based on Historical Data

The precipitation hydrograph analysis, spanning from 2013 to 2023, revealed that the highest rainfall intensity was recorded on June 14, 2015, at a rate of 3.66 millimetres per hour.

Relying solely on historical data for flood simulations can be problematic because historical records may not encompass all possible flood scenarios, especially under changing conditions like urban development and climate change. Statistical return periods, on the other hand, provide a broader and more adaptable perspective. They estimate the probability of various flood magnitudes over time, integrating historical data with statistical models. This approach is more useful for future risk management and planning, as it accommodates a wider range of scenarios and can be adjusted for ongoing environmental changes.

The results of the simulation are provided below:

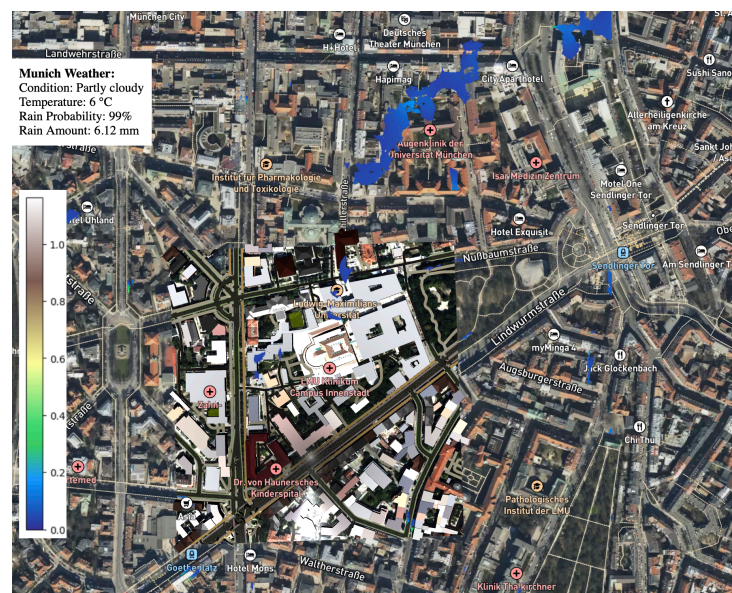


Figure 36 Rainfall data from Historical data taken from Web application.

From the simulation we understand from the historical data of 3.66mm for 10-hour duration there is not much effect on the LMU hospital campus. We find at most 1 cm to 7 cm of flood in northeast part of our area of interest which consists of the Portalklinik building.

However interestingly we find some chance of 20 cm of flood at the Augenklinik der Universität München.

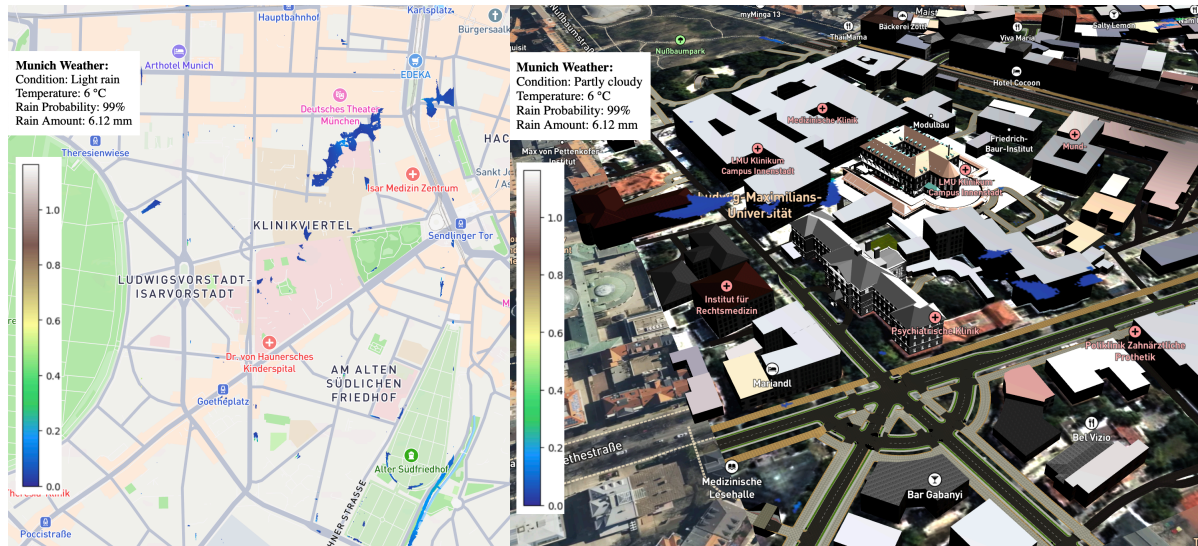


Figure 37 Rainfall simulations results from Historical data taken from Web application.

4.2 Simulation results from Statistical Data

4.2.1 Result from 10-year return period

Statistical return periods are crucial in flood simulations as they offer a probabilistic assessment of flood risks over time. This approach, unlike reliance on historical data alone, accounts for the likelihood of various flood magnitudes occurring within specific time frames, such as the infamous "10-year flood." This methodology integrates historical flood data with advanced statistical models, allowing for a more comprehensive and forward-looking analysis. It's particularly valuable in the context of climate change and urban development, where flood patterns and risks are evolving. By using statistical return periods, planners and policymakers can better anticipate and prepare for future flood events, ensuring more effective risk management, infrastructure planning, and emergency response strategies. This approach is instrumental in mitigating potential flood impacts in both short-term and long-term scenarios.

The results shown below are from KOSTRA 10-year return period of data:

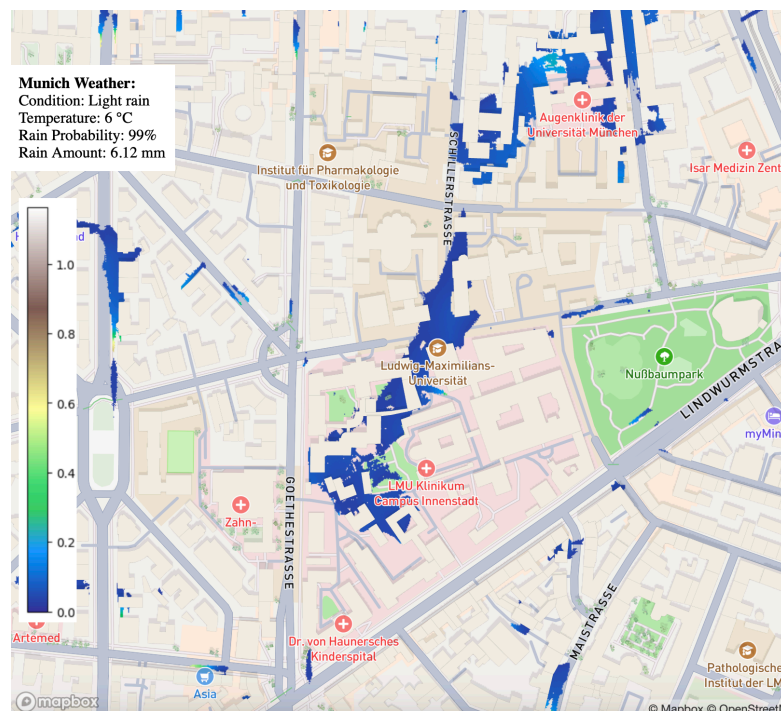


Figure 38 Rainfall simulation results for 10-year return period data taken from Web application.

The above results get interesting as we could find with this intensity of rainfall it would be most likely to affect the northeast part of our area of interest with flood levels reaching from 1 cm to 10 cm and at most 20 cm between the psychiatry building and portal clinic.

4.2.2 Result from 100-year of return period

A 100-year return period flood simulation which was asked from the water department, though not mandatory, as it serves as a key benchmark in flood risk assessment and urban planning. This type of simulation helps identify the potential impact of a severe flood, guiding the development of resilient infrastructure and effective emergency response plans. It is also often used to meet regulatory requirements and for insurance purposes, as it represents a balance between extreme events and practical planning needs. While not the only scenario to consider, the 100-year flood simulation plays a crucial role in preparing for and mitigating significant flood risks.

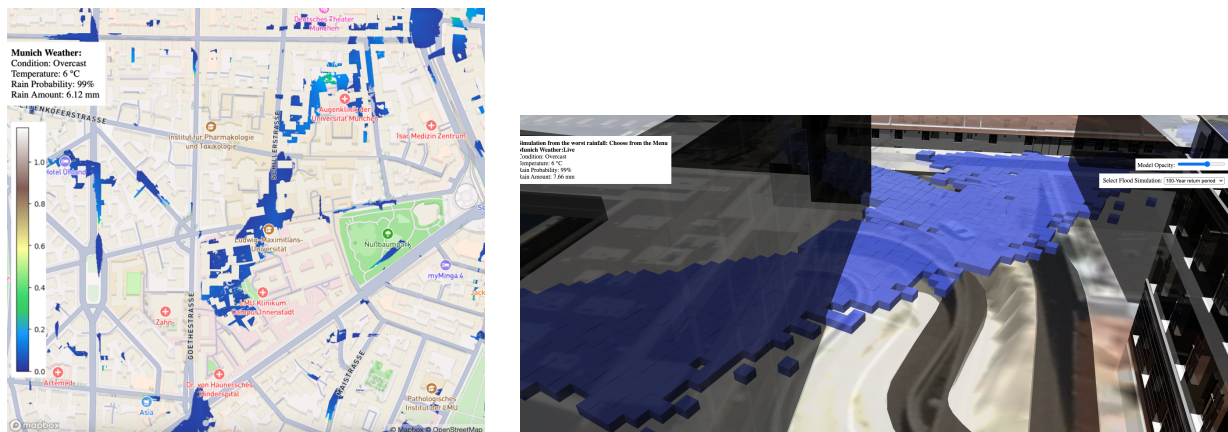


Figure 39 Rainfall simulation results for 100-year return period data taken from Web application.

The results show 0.1 m to 0.2 m of flooding in our area of interest mostly on the Psychiatry clinic. However, we see high vulnerability in the northeast part near Augenclinic with flood levels reaching 0.4 to 0.5 m which could produce devastating results.

However, as these results are from a 100-year return period these results are likely to occur.

4.3 Simulation results from ML prediction model

When we run our prediction of rainfall for the month of June 2024 as it's the month with the worse rainfall from the historical data it came around to be 96.09 mm of average, which is well below the data we derived from KOSTRA statistical model. Thus, it's obvious the results are good enough to have any effect on our area of interest. As of now our machine learning model only takes the historical rainfall as a model input, by feeding a neural network with not only rainfall patterns but also incorporating variables such as humidity levels, wind velocity, and other climate change indicators, we can create a more robust and accurate predictive model.

This approach allows the neural network to learn from the intricate interactions between various weather elements and their cumulative effect on flood risks. For instance, high humidity combined with specific wind patterns might increase the likelihood of heavy rainfall, a nuance that our current model might overlook. Furthermore, including climate change data can help adjust predictions based on long-term environmental shifts,

offering a more forward-looking perspective on flood risks. Which might be an interesting future scope of this project.

4.4 Visualization from Unreal Engines

From the results derived from above we make a visualisation with unreal engines considering the 100-year return period rainfall which caused almost 20 cm flood level near the psychiatry building.



Figure 40 Rainfall simulation in Unreal Engines

5 Conclusion

The analysis of flood risk at the LMU campus, specifically in the Zimmensblock area of Munich, has demonstrated a minimal threat from heavy rainfall events. This conclusion is supported by comprehensive studies that utilized historical data, machine learning models, and statistical analysis.

Analysis of historical flood data, indicating a rainfall intensity of 3.66mm over a 10-hour period, demonstrates minimal impact on the area of interest. This observation holds even under the assumption that all sewage pipes are operating at full capacity, with flood levels ranging merely from 2 to 7 cm—a magnitude of effect that can essentially be disregarded. The employment of a machine learning model, specifically utilizing the Random Forest algorithm, yields simulation results that align with these observed low flood levels. This concurrence is attributed to the model's training on past historical data alone, without incorporating other significant factors that influence flooding. Nonetheless, as previously mentioned, there exists potential for enhancing the accuracy and predictive capability of this machine learning model in future analyses by integrating a broader spectrum of influencing factors.

When considering the statistical data from KOSTRA, we concluded some interesting results:

In the scenario of rainfall with a 10-year return period, flood levels ranging from 2 to 20 cm are anticipated at the Psychiatry building of the LMU campus. However, these levels fall well below the building's threshold, rendering it safe from flooding in the foreseeable future.

Conversely, for a 100-year return period, predicted flood levels span from 20 cm to 40 cm. In this instance, the primary concern shifts towards pedestrian safety, rather than the integrity of critical infrastructure, which is expected to remain largely unscathed.

In summary, the collective evidence from historical records, machine learning simulations, and statistical projections points to a **minimal** flood risk for the LMU campus in Munich's Zimmensblock area. Yet, the drainage system shows signs of stress in certain areas for example J15, necessitating targeted improvements to ensure continued

resilience against flooding, particularly as climate patterns evolve and the potential for extreme weather events increases. Further studies and future and model refinements could be made to address these localized concerns and to enhance the predictive capabilities for future flood scenarios. While certain extreme weather events could present challenges, the current infrastructure and building designs appear well-equipped to mitigate these risks effectively.

6 Discussion

The integration of sophisticated computational tools and methodologies significantly improves our understanding and capability to forecast and manage environmental and structural challenges in urban areas. This discussion compiles insights from the application of ArcGIS and IFCopshell for construction project data management, the study of rainfall intensity and its impact on urban flooding, and predictive modelling of future rainfall events, offering perspectives on urban planning and infrastructure resilience. By utilizing `IfcProjectedCRS` and `IfcMapConversion` entities, projects can now incorporate precise geographical data into IFC files, enabling more accurate and automated data handling. This advancement is key for aligning project data with geospatial reference systems, thus boosting the interoperability and accuracy of construction project management. Nonetheless, the adoption and comprehension of these capabilities remain a challenge, essential for enhancing project coordination and efficiency.

The highest recorded rainfall intensity serves as a crucial metric for assessing flood risk and simulating worst-case scenarios. The specific flooding around node J15 and the surcharge in several conduits emphasize the need for thorough drainage network analysis in urban planning. These insights suggest that infrastructure might need upgrades or redesigns to handle the increasing rainfall intensity, which climate change may intensify. Additionally, the development of a web application for this project significantly enhances data visualization and interaction. Built using JavaScript and HTML, this application loads GLB models of the targeted area, displaying the elevation of floods relative to IFC-structured buildings as GLB models with various flood prediction results. This tool not only provides a dynamic platform for analyzing flood impacts but also facilitates a deeper understanding of flood elevations in relation to urban infrastructure, further enriching the project's contributions to urban planning and resilience efforts. Simulation results reveal significant flood level variations across the LMU hospital campus, demonstrating a detailed understanding of how rainfall intensity affects specific urban areas. Such findings are vital for targeted interventions and allocating resources to highly vulnerable areas like the Augenklinik der Universität München.

While the predictions indicate lower-than-expected rainfall, the application of machine learning models holds promise for improving the accuracy of such forecasts. By incorporating a broader range of climatic variables, future models can offer more reliable predictions, thus better informing preparedness and mitigation strategies. However, this approach necessitates a continuous refinement of models and integration of up-to-date data to reflect changing climate patterns accurately.

The findings from this thesis underscore the interdependence between technological advancements in data management, analytical precision in environmental assessment, and the imperative for adaptive urban planning. As cities continue to grow and face the multifaceted challenges posed by climate change, the integration of sophisticated computational tools and methodologies will be paramount in crafting resilient and sustainable urban environments. Future research should focus on expanding the datasets and variables involved in predictive modelling, alongside exploring the implications of these technologies in broader urban contexts. The journey towards resilient urban infrastructure is iterative, requiring ongoing assessment, adaptation, and innovation.

7 Methods For Flood Mitigation

The devastating flood disaster of July 2021, particularly in the states of Rhineland-Palatinate and North Rhine-Westphalia, underscored the catastrophic potential of natural calamities, resulting in the tragic loss of over 180 lives and leaving around 800 individuals seriously injured. Thus, it gets very important for simulating and understand potential flood threat levels in the historical location of Munich. Although, from the simulation results we didn't find much vulnerability in our area of interest even from the 100 year of return period if flood still it gets very important to prepare for unseen situations considering climate change.

These techniques include avoiding construction on floodplains, creating urban "sinks" to hold water, implementing green infrastructure such as green roofs and permeable pavements, utilizing underground systems like soakaways, and engaging households in adopting private-side flood protection measures (Qin, 2020). Urban planning should be adaptive to climate change, and a paradigm shift has occurred in flood management, emphasizing softer approaches and the integration of natural systems into urban planning to increase resilience to flooding. These techniques aim to reduce the risk to houses, schools, hospitals, businesses, and other key infrastructure, ultimately enhancing the city's ability to withstand and recover from flooding events.

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8 List of Figures

Figure 1 Innenstadt clinic LMU.....	2
Figure 2 Overview of the developed method and workflow.....	3
Figure 3 Different Layers in the model	8
Figure 4 Water distribution in ArcGIS.....	9
Figure 5 IFC model of Psychiatry clinic	13
Figure 6 2D CAD model of the Zimmensblock area	14
Figure 7 Different Layers in the DTM and DEM (Štular, Benjamin & Eichert, Stefan & Lozić, Edisa, 2021).....	15
Figure 8 Elevations of the Zimmensblock area in QGIS	17
Figure 9 Different Level of Detail as in CityGML (An Improved LOD Specification for 3D Building Models, 2016)	18
Figure 10 CityGML LoD2 of the Zimmensblock area.....	19
Figure 11 Georeferenced CAD model in Civil3D.....	22
Figure 12 Georeferencing IFC in ArcGISPro	23
Figure 13 Georeferencing IFC in ArcGIS Pro	24
Figure 14 Diagram of georeferenced IFC in IFCopenshell.....	25
Figure 15 Converting Elevation into TIFF images.	26
Figure 16 Model X in Infraworks	28
Figure 17 HEC-RAS Dashboard	32
Figure 18 Elevations in HEC-RAS.....	34
Figure 19 Catchment area for our area of interest.....	35
Figure 20 Boundary conditions as set in HEC-RAS.....	35
Figure 21 Interface as in Fast Flow application	36
Figure 22 Sentinel 2 imagery on Land Cover	41
Figure 23 Manning’s coefficient with respect to land cover.....	42
Figure 24 Munich clay content map from SoilGrid.....	42
Figure 25 Simplified Random Forest algorithm (Koehrsen, 2020).....	43
Figure 26 Picture of Infraworks FBX export window	50
Figure 27 Picture of Model X in blender	51
Figure 28 Model X in the web application.....	52
Figure 29 Rainfall data with elevation	54
Figure 30 Flood elevation bar as in web application.....	56
Figure 31 Picture of alerts in vulnerable areas.....	57
Figure 32 Clickable features inside web application.....	57
Figure 33 Zimmensblock on unreal engines	58
Figure 34 Pipe Network simplified of LBD from StBA München	61
Figure 35 Results from SWMM.....	64

<i>Figure 36 Rainfall data from Historical data taken from Web application.</i>	<i>67</i>
<i>Figure 37 Rainfall simulations results from Historical data taken from Web application.</i>	<i>68</i>
<i>Figure 38 Rainfall simulation results for 10-year return period data taken from Web application.</i>	<i>69</i>
<i>Figure 39 Rainfall simulation results for 100-year return period data taken from Web application.</i>	<i>70</i>
<i>Figure 40 Rainfall simulation in Unreal Engines.....</i>	<i>71</i>

9 List of Tables

<i>Table 1 Historical Rainfall data</i>	29
<i>Table 2 Annual Rainfall for Each Year</i>	30
<i>Table 3 Year v/s Rainfall in each month</i>	31
<i>Table 4 Rainfall intensity from historical data</i>	37
<i>Table 5 Statistical data from KOSTRA</i>	38
<i>Table 6 Precipitation Hydrograph</i>	39
<i>Table 7 Mean Annual Rainfall data.</i>	44
<i>Table 8 API service listings of weather API</i>	48
<i>Table 9 Web application Architecture</i>	51
<i>Table 10 Chart showing sub catchment runoff.</i>	62
<i>Table 11 Chart for Node flooding</i>	62
<i>Table 12 Chart showing node depth.</i>	63
<i>Table 13 Chart for outfall loading</i>	63
<i>Table 14 Chart for conduit surcharge</i>	63
<i>Table 15 Chart showing link flow.</i>	64

10 Declaration

I hereby declare that I wrote this Master's thesis independently. Only the sources and aids explicitly named in the work were used. I have identified ideas that have been taken over literally or figuratively as such.

I also certify that this work has not yet been used as the basis for any other examination procedure.

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