# Near Real-Time Responsive Flood Event Representation: An Open-Source Interactive Web Application Architecture

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**Abstract**

The adoption of accessible Digital Twin technology in flood applications has been impeded by a notable lack of practical examples. Arguably, the most distinguishing feature of Digital Twin technology is the integration of near real-time data analytics through IoT sensor connectivity, which has remained underutilised in flood applications and therefore indicates a critical research gap. This project endeavoured to develop a comprehensive and replicable open-source architecture framework, specifically tailored for near real-time responsive flood event representation. The resultant interactive web application integrated near real-time river height and rain fall data streams and performed on-demand data analytics. Key results include the establishment of a back-end spatial database, a coupled physical city and digital space model, and a functional holistic front-end user interface. Additionally, this research aligned with the Gemini Principles by emphasising data interoperability and maintaining an information feedback loop. The study also aimed to configure near real-time IoT sensor connections, implement event triggers, and deliver interactive visualisations in an easily accessible format. The research addressed key questions surrounding the effective integration of IoT sensor data, identification of crucial flood indicators and parameters, and rapid quantification of flood event impacts. Ultimately, this research project demonstrates how Digital Twin technology can swiftly provide decision-makers with crucial insights during flood disaster events.

## 1. Introduction

### 1.1 Background

Floods are a particularly threatening disaster with extremely damaging effects and costly implications. In an Australia context, both the severity and frequency of heavy rainfall events in recent years have been looming larger in tandem with the ever-increasing presence of climate change (BOM and CSIRO, 2022). Due to this, the risk of flash floodings in urban areas has also subsequently increased (Bruyère et al., 2019). In response to this clear threat, concerns are raised about flood response strategies. It is clear that constant improvement in strategies related to flood management are necessary, and advancements in digital technologies can help respond to this.

Digital technologies can contribute to flood management efforts by minimising the impact of floods when they occur by informing important decision-making. In recent years the concept of a Digital Twin has gained a strong foothold. First proposed by Michael Grieves in 2003, a Digital Twin is a virtual or digital equivalent to a physical product. Over the past two decades since, technology has advanced to the point where not only products, but entire cities can be virtually modelled as a Digital Twin. Due to its exciting potential, the concept of a Digital Twin "is increasingly at the core of most smart city initiatives, as it has been identified as a critical tool for tackling the challenges of this century" related to "urban liveability and climate adaptability" (Diakite et al., 2022). Also possessing similar concepts, the application of flood management is well-positioned to make use of this technology.

A successful Digital Twin depends on several components, arguably the most important of which is near real-time data integration. The successful integration of this consequently enables near real-time data analytics which defines the core essence of Digital Twin technology. Consistent and reliable data sources integrated through an efficient workflow helps ensure a reliable product of high quality. Once achieved, this further ensures a successful Digital Twin technical framework, especially in the context of flood modelling in the sense that "real-time analytics are critical for increasing situational awareness and timely decision-making" (Langenheim et al., 2022). Related to this also is the idea of regular data maintenance as a key consideration of Digital Twins. It is further emphasised how "building a city digital twin is an ongoing process as new data can be continuously acquired and used to update the state of the digital twin in order to enhance its reliability" (Ghaith et al., 2022). A key to achieving this crucial condition is 'Internet-of-Things' (IoT) sensor-based technology which enables the integration of near real-time data analytics.

Several sensors classed under the generic abbreviation of IoT already exist in developed cities, and opportunity exists for the integration of their data into a Digital Twin. Coined by British technologist Kevin Ashton in 1999, the abbreviation IoT is used to describe the increasing connectedness between humans, machines, and the Internet through digital ecosystems that "enable higher productivity, better energy efficiency, and higher profitability" (Tripathy and Anuradha, 2017). IoT sensors help detect, measure, and reflect the current state of real-world phenomena, such as temperature, humidity, rainfall, river level heights etc. Once effectively harnessed, event triggers can be designed to trip once the incoming data streams surpass a pre-defined threshold. In this way, it can be seen how the harnessing and monitoring of this constantly updating data stream through near real-time data analytics can help further enrich Digital Twin technology.

### 1.2 Rationale, Aim and Objectives

The core concept of Digital Twin technology is a relationship between physical and digital space, maintained through a live feedback loop of near real-time data analytics and informed decision making. This is enabled through the efficient integration of near real-time IoT sensor data. This research project will investigate practical means of realising this concept through the application of flood event representation and interaction, as a

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means to demonstrate the inherent value of Digital Twin technology. The following technical objectives have been determined to support the research aim:

a. Establish a conceptual and methodological framework to identify and define the essential components for the realisation of near real-time flood event representation and interaction;
b. Develop a robust spatially enabled database system capable of efficiently storing diverse sets of geographical, topographic, environmental, and building data to populate the static basemap;
c. Implement interactive 3D digital representation to ensure a faithful portrayal and rendering of the physical characteristics within the defined study area;
d. Source and configure Internet of Things (IoT) sensor connections to the overall infrastructure, enabling the acquisition of timely and relevant near real-time information;
e. Establish and fine-tune event triggers that activate when IoT sensor data inputs surpass predetermined threshold values, thereby ensuring a prompt response to critical flood-related information;
f. Disseminate the flood application in an easily accessible format that dynamically reflects changes in real-world conditions and provides clear and intuitive visualisations of flood scenarios.

From the aim and technical objectives, the following research questions have been designed for the comprehensive investigation and development of an open-source framework tailored for near real-time responsive flood event representation: How can IoT sensor data be effectively integrated into an open-source architecture to enable near real-time flood event representation and interaction? (RQ1) What are the key indicators or parameters necessary to effectively represent flood extents? (RQ2) How can this technology be used to quantify impacts of flood events in near real-time? (RQ3).

## 1.3 Literature Review

### 1.3.1 Open-Source Technical Framework

The practicality of an interactive digital tool realised through a near real-time data analytics framework enabled through IoT sensor connectivity and integration of event triggers is largely determined by its technical architecture. A framework supported by a concise software stack which effectively manages all the elements and allows for communication between them is crucial for a successful product.

In the design process of this technical framework, the use of open-source technologies and adherence to Open Geospatial Consortium (OGC) standards promotes the idea of free science and open accessibility. As outlined in a study by Santhanavanich et al. (2022), a spatial data infrastructure for managing building energy in an Urban Digital Twin (UDT) was developed with adherence to OGC standards as a means to increase data usability and efficiency. In this way, interoperability between various data layers and client applications was enabled, and temporal energy data was successfully integrated in a manner that "improves the loading efficiency of geospatial data into UDT applications" (Santhanavanich et al., 2022). This idea of accessibility is also demonstrated by Diakite et al. (2022), wherein it was concluded that "a functioning digital twin can be built using already existing data and open-source technologies". The project presented ways in which Digital Twin technology can contribute to sustainable urban development in the city of Liverpool, New South Wales, Australia. One notable aspect of this project is the way in which the technical architecture carefully considers how communication between database and front-end is achieved through the use of custom Application Programming Interfaces (API). This technicality is vital to the success of the overall model, as it also used to achieve IoT sensor integration. Despite the lack of a flooding context in both these examples, the concept of IoT sensor integration is in the application of real-world contexts is apparent.

### 1.3.2 IoT Sensor Data

As previously mentioned, the key factor that separates Digital Twin technology from static digital city models is the integration of near real-time analytics achieved through the integration and management of IoT sensor data. IoT sensor data can be integrated into a Digital Twin technical framework through an Application Programming Interface (API) which is a cloud-based tool that allows for the communication and transfer of data between applications. However, IoT sensor data is often unstructured or semi-structured and contains multiple variables for each observation which are continuously streamed from a remote sensor (Li et al, 2020). This relates to the key challenge of data interoperability which remains to be a key barrier to wider adoption of Digital Twin technology. Yet, this concept concerning APIs providing data transfer between IoT sensors and web-based front-end systems has been previously proven (Major et al, 2021; Platenius-Mohr et al, 2020; Zhu et al, 2016; Yulia et al, 2021). It is crucial for IoT sensor data to be delivered in a data format that allows for efficient communication of derived information.

### 1.3.3 Data Interoperability in Digital Twin Applications

Further challenges are presented by the large-scale and complex nature of flooding in relation to the collection and integration of consistent and reliable data necessary for multidisciplinary modelling. Langenheim et al. (2022) tackles these challenges by investigating the tools and workflows required in the context of "real-time water sensitive urban design decision-making". Managing data sources from various sources such as GIS, BIM, and IoT sensors all increase the complexity and technical requirements of a technical framework, especially in the database stage. Langenheim et al. (2022) focuses on this issue of inconsistent data sources and suggests "considerable adjustments to future data collection methods" are required in this particular context. Furthermore, the priority of developing efficient workflows for visualising complex geometry is highlighted. This notion is corroborated by Ghaith et al. (2021) in which it is stated how "immense data" is required for building a city Digital Twin for the purpose of flood imitation. The study lays a framework to "facilitate the development of city Digital Twins" whilst also highlighting the fact that this is still an emerging tool and technology. The framework design is based upon interdependence between several infrastructure systems including water, power, and transport to simulate city behaviour (Ghaith et al., 2022). Subsequently, this introduces data schema compatibility issues between these various systems. Further addressed by Teng et al. (2017), "inter-model, inter-discipline approaches can take advantage of the merits of various approaches while avoiding shortcomings". However, due to the complex nature of Digital Twin architecture, this persisting issue of data interoperability continues to exist and is a threshold developing efficient Digital Twin architecture.


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Furthermore, as part of a recent industry and research collaboration study on Digital Twin technology for flood resilience in New Zealand, heavy importance was placed on understanding the differences and difficulties surrounding data of varying spatial scales from varying sources (Wilson et al., 2022). Stoter et al. (2020) further corroborates this by explaining how "the conversion of semantic 3D city models from one format to another is challenging, both from a geometric point of view and because of incompatible semantics". Data standardisations around 3D city building models can help address this. Karim et al. (2021) explains how CityGML is now the standard for digital twin city model development. Standardised by the OGC with five levels of detail, this data schema can be managed and organised using database tools.

## 2. Methods

### 2.1 Conceptual Framework

The conceptual framework of the project is outlined in Figure 1, in which a mutual relationship between reality itself and the flood event representation and interaction is constantly maintained. In this way, an information feedback loop incorporating live IoT sensor data is created, which allows the integration of near real-time data analytics in the virtual space to enable informed decision making in physical space. The key condition of this is harnessing the data output of IoT sensors in an effective way that allows for the flow of information feedback back towards reality.

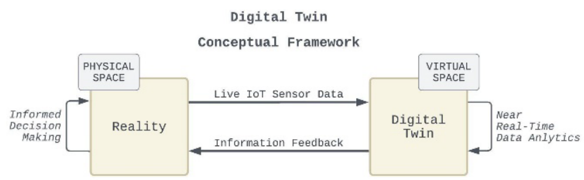
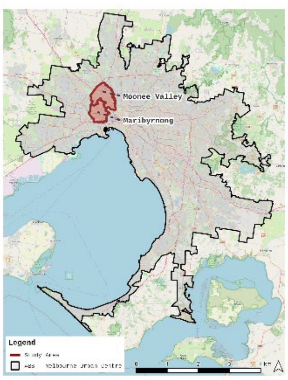



Figure 1. The core concept of a Digital Twin system is a mutual relationship constantly maintained between virtual and physical

### 2.2 Study Area and Weather Stations

Within the context of the Melbourne Urban Centre as defined by the ABS (2024), the study area is defined as the two Local Government Areas of Moonee Valley and Maribyrnong in Melbourne's north-west as seen in Figure 2. This study area has a history of flooding events due to the Maribyrnong River's close proximity to various other natural watercourse features. Figure 3 shows the locations of the four weather stations from which live API data is fetched.



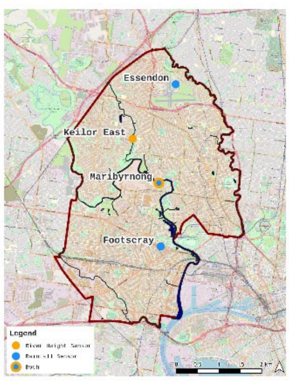




Figure 2. (left) Study area capturing the flood-susceptible Maribyrnong River running through the centre.

Figure 3. (right) Melbourne Water weather stations.

### 2.3 Datasets

Various static and live data are used in this research project. Focus has been placed on the use of free, open-source data in OGC standard recognised formats. The study area boundary is sourced from "Local Government Areas – 2022 – Shapefile", sourced from the Australian Bureau of Statistics (ABS). The "Vicmap Elevation 10m DEM" (Digital Elevation Model) provided by the Victorian Government Department of Energy, Environment and Climate Action is used to represent the ground surface of the study area. The 3D buildings are a subset of "Vicmap 3D Buildings" sourced from the recently released Digital Twin Victoria platform. The permanent water bodies are represented by the Water & Waterways polygons extracted from OpenStreetMap using GeoFabrik Downloads. Lastly, the river height and rainfall APIs used to derive near real-time analytics are an authoritative data source provided by Melbourne Water.

### 2.4 Workflow

#### 2.4.1 Overview

Figure 4 shows the technical architecture diagram, specifying the three stages of Database, Application, and Front-End.

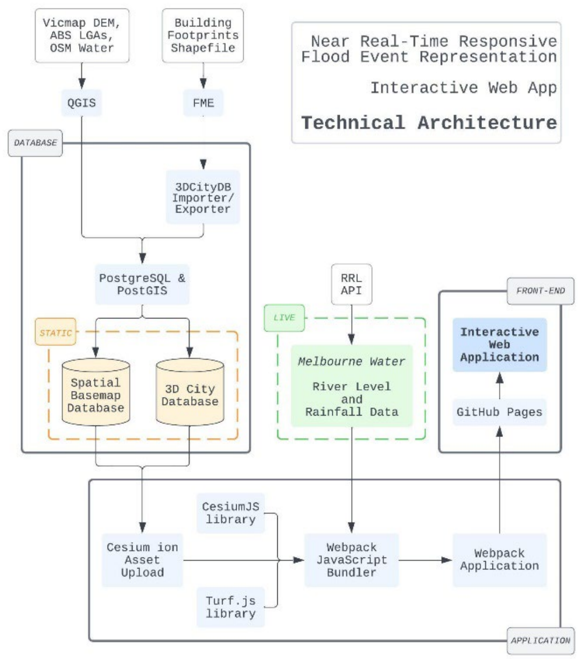



Figure 4. Technical architecture overview diagram, notably demonstrating the integration of the Melbourne Water API.

#### 2.4.2 Database Development

Digital entities that make up various elements of the virtual environment are stored in the Spatial Basemap Database. Firstly, the Vicmap DEM raster, ABS Local Government Area polygons, and OpenStreetMap Water polygons are clipped to the study area and then re projected into EPSG:4326 WGS 84 using QGIS. The Building Footprints Shapefile is also processed in a similar way. Using FME, the original file possessing 81,084 total building footprints for the study area is converted from Shapefile to CityGML format.

Next, two empty PostgreSQL databases are created using the pgAdmin tool. The PostGIS extension is enabled in both databases to allow for the management of spatial data. Then, using the DB Manager in QGIS, all the raster and vector data is uploaded into the Spatial Basemap Database. For the 3D City Database however, another tool called 3D City Database Importer/Exporter is required. This tool takes the output CityGML file from FME, maps it into a relational database schema and then imports it into the empty PostgreSQL/PostGIS Database, as outlined in a tutorial by the Chair of Geoinformatics at the Technical University of Munich (2016).

#### 2.4.3 Integrating IoT Data Streams

In the Application stage of the technical diagram, the data is then exported from the two databases and manually uploaded to Cesium ion. This method ensures that all the data necessary for the virtual environment is accumulated into a single location, emphasising the concept of data integration.
Next, IoT data streams are integrated through the Melbourne Water API. Transmitted through radio waves, this live RRL data stream of river level and rainfall data is harnessed by a JSON URL hardcoded into the JavaScript source index file. A combination of this fetched live river level height and accumulated rainfall data over the past 24 hours is used to determine whether or not the current weather conditions imply flood risk, and if so, to what extent the flood water would reach. A flood height variable is computed based on the live data fetched from the API and used to buffer the normal-state water body polygons. Live river height data is integrated to further inform the buffer distance where the greater the accumulation of rainfall over the past 24 hours, the greater the extent of the computed flood polygon. A rainfall threshold value of 40 mm is defined, from which any fetched data greater than this value will trigger a flood extent polygon to automatically be added to the front-end interface. This value is derived from Melbourne Water’s 53rd document submission to the Maribyrnong River Flood Review detailing a significant flood event that occurred in October 2022 (Melbourne Water, 2023). Visual comparisons between the flood extents shown in “Map 1” on page 11 of the document and the flood buffer extents generated by the visualisation are used to validate the extents produced for the particular study region.

JavaScript libraries are used to further develop functionality. CesiumJS is used to build the stage, define “Esri World Imagery” from ArcGIS Map Service as the basemap imagery provider, and import data from Cesium ion using an access token URL. Turf.js, an open-source JavaScript library for geospatial analysis is implemented to create the flood extent buffer polygon and calculate relevant flood statistics.

#### 2.4.4 Computing Near Real-Time Statistics

These flood statistics are computed through interactive buttons displayed to the user in the interface. In total, the interface has four buttons on the left-hand pane, separated into two categories based on colour. The two green “fetch” buttons return live data from the Melbourne Water API. The first button fetches live river level height as the mean reading of the Maribyrnong“ and “Keilor East” weather stations. The other green “fetch” button returns the rainfall for the last 24 hours as the mean reading of the three weather stations “Maribyrnong”, “Essendon” and “Footscray”.

The other two “calculate” buttons perform near real-time data analytics based on the data fetched by the green buttons. The number of flood affected buildings are calculated using the open-source JavaScript library for geospatial analysis named Turf.js. The calculation is performed server-side within the index.js script by determining the count of building footprints that lie within the buffered flood extent region. This total count is added to the interface and expressed as a number. The second red “calculate” button returns the total flooded land area using Turf.js by firstly computing the area of water bodies in their normal state, and then returning the difference with the buffered flood extent. This value is expressed in square kilometres and presented as the total flooded land area. In particular, the turf.area function is used, which is derived from Chamberlain and Duquette (2007) and shown in Equation 1.

$$A = -\frac{R^2}{2}\sum_{i=0}^{N-1}(\lambda_{i+1} - \lambda_{i-1}) \cdot sin_{\phi_i} \quad (1)$$

where $A$ = area of the polygon
$R$ = radius of the Earth
$i$ = each vertex of the polygon
$N$ = total number of polygon vertices
$\lambda_i$ = longitude of point $i$
$\phi_i$ = latitude of point $i$

This formula describes the inner mechanism of the turf.area function used to calculate the total flooded land area. Based on geospatial theory, the formula simplifies and collects terms by latitude to give the area of a polygon on a sphere and calculate an approximate signed geodesic area of a polygon expressed in square meters. This inner mechanism is entirely hidden from the user however to ensure readability; one of the core themes kept in mind when designing the user interface.

#### 2.4.5 Designing an End-User Experience

The user interface is created using CSS code with reference to the associated JS and HTML files. The title, description, legend, weather station points and four interactive buttons are all created and referenced within the JavaScript source index file. The visualisation of the flood extent is defined in this code as a transparent blue polygon draped over the surface of the terrain which allows for clear visual identification of affected buildings. Finally, this JavaScript, HTML and CSS code is compiled into a Webpack Application and readied for deployment to the internet. The Webpack application is pushed to a GitHub repository and the associated GitHub Pages functionality publishes the application. Access to the web application is achieved through a simple URL.

## 3. Results

### 3.1 Coupled Physical Reality & Web Application

This result of this research project is a Cesium-based Webpack JavaScript application that uses live API data feeds and the Turf.js library to mirror physical reality in a digital space for the purposes of flood event representation and computing derived flood statistics in near real time. It can be described as a cyber physical system, in which changes that occur in the reality are visualised in the user interface. Visual representations of flood water height changes along the Maribyrnong River and within the study area update in the application as they occur in the reality.

The web application also allows users to fetch a live river height reading expressed in metres and a live rainfall data reading for the previous 24 hours expressed in millimetres. The integration of this API accumulates readings from nearby relevant weather stations and calculates the mean to produce a final reading of the study area. In this way, the web application integrates IoT data, performs data analytics, and visualises derived impacts in a meaningful way. Once rainfall levels exceed the 40mm threshold and a flood extent visualisation is created, the web application is then able to calculate statistics. The total count of buildings affected by the computed flood extent and total flooded land area expressed in square kilometres are calculated using Turf.js. In this way, the web application provides a technological solution to quantify impacts of flood events localised to the study area in near real time.

As well as adhering to OGC standards, the use of free software tools further promotes the idea of accessibility and open science. This research projects presents a proof of concept for a web application based on the core concept of Digital Twin technology and a base technical framework from which further technical developments can develop from.

### 3.2 Web Application Interface

The Webpack application build has been published via GitHub Pages as a means of allowing easy access to the through a URL. Online hosting using this method means that any user with an internet connected device can experience and use the web application.

Because of this broad accessibility, the end user experience has been kept in mind during the design of the web application through careful consideration of the front-end interface. A natural function of Cesium is allowing the user to interactively zoom, scroll, pan, and explore the digital city space. This functionality has been maintained in the web application, and further custom functions have been designed. As seen in Figure 5, four interactive buttons in two different categories are presented to the user that either fetch live data or compute statistics in near real time. The main map stage also has four points styled in blue, orange or both to signify the geographical locations of the river height and rainfall sensors as previously described in Figure 3. A descriptive legend in the bottom right ensures an interpretable interface.

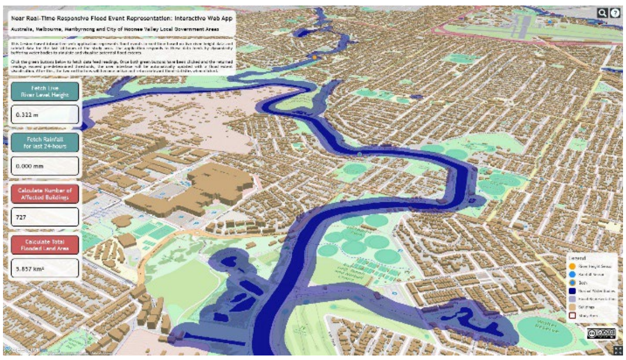



Figure 5. User interface demonstrating the flood buffer represented by a semi-transparent blue overlay that drapes over the surrounding terrain and buildings.

The culmination of these process is available to view in the web application available through the following URL:

https://ryn-trnr.github.io/NearReal-TimeResponsiveFloodEventRepresentation/

## 4. Discussion

### 4.1 Alignment with Literature and Digital Twin Principles

The integration of flood Digital Twin concepts and methodologies in this study aligns with a growing body of literature dedicated to advancing flood resilience and disaster management. The use of Digital Twins, as demonstrated in studies such as Ghaith et al. (2022) and Langenheim et al. (2022), offers a powerful framework for simulating and analysing flood events with consideration of near real-time data implementation. As a contribution to the broader discussion on the application of Digital Twin technology for flood imitation and urban design decision-making, the approach developed in this research leverages high-resolution sensor data and 3D city models. The utilization of LiDAR data for enhanced terrain modelling (Wilson et al. 2020; Bacher 2022) and the integration of land use classifications (Shen et al. 2020) for accurate flood extent predictions further solidify this study within the flood Digital Twin discourse. These approaches represent advancements in data acquisition and processing techniques that are central to improving the accuracy and reliability of flood event representation. Moreover, the consideration of near real-time data integration and visualisation aligns with studies by Martinis et al. (2009) and Mure-Ravaud et al. (2016), highlighting the critical importance of timely information for effective flood forecasting and response. This research’s emphasis on near real-time capabilities strengthens its contribution to the ongoing dialogue surrounding operational flood detection and forecasting systems.

### 4.2 Revisiting Digital Twin Objectives

This research resonates with various organisations globally who have proposed guidelines for the development of Digital Twin technology. Proposed in 2018, The Gemini Principles are deliberately simple and broad guidelines for information management and the UK‟s National Digital Twin. As a broad overall level, it states how Digital Twins must be primarily for public good and possess the three founding values of a clear purpose, trustworthiness, and efficient function (CDBB, 2018). Further refinement and adoption of these principles for an Australian context are present in the ANZLIC Spatial Information Council’s Principles for Spatially Enabled Digital Twins of the Built and Natural Environment (ANZLIC, 2019). The principles are ordered in a hierarchical structure and addressed as following:

#### 4.2.1 Public Good

The demonstrated web application maintains a core principle of delivering public good by facilitating access to spatial data visualisations and non-sensitive derived insights in the context of flood event representation. Shared and open access to the application is achieved through a web application accessible to any person with an appropriate internet-connected device.

Another objective of the web application is concentrated around the idea of providing an “effective decision support tool that can enable proper and rapid actions under flood events” (Ghaith et al., 2022). In this way, the location-based statistics generated by the web application can help yield increased productivity in times of flood disaster events.

#### 4.2.2 Function and Form

Data quality is indicated by acquirement through reputable sources. The API used in this project is managed by Melbourne Water, the Victorian Government-owned statutory authority that controls and manages much of the water bodies and water supply in the metropolitan Melbourne area. It is the authoritative data source for environmental water observation and data collection in the study area.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Relating to the idea of adapting to a changing world and its changing technology, the design of the web application is flexible and allows for iterative improvements. The architecture and particular combination of technologies allows for further refinements and the adaption for enhanced functionality. Being Cesium-based, the web application is well positioned for this notion due to the constantly progressing nature of this established JavaScript library for software-development in 3D geospatial applications.

#### 4.2.3 Governance and Accountability

The web application is underdeveloped in this particular principle; however, all the various elements of the web application adhere to OGC standards as a means to ensure overall data interoperability, compatibility and functionality. Simple Features, GeoJSON, GeoTIFF, CityGML, 3D Tiles are all data schemas all support an approved OGC Implementation Standard (OGC, 2023).

### 4.3 Applications

This research project demonstrates the potential for Digital Twin technology to broaden the scope of digital responsive flood event representation through the implementation of near real-time data analytics and ease of accessibility. As a proof of concept, the web application demonstrates three key use cases; (1) Live, free, open-access, interactive city model for visualisation of flood events in near real-time; (2) Live rainfall and river height IoT sensor data fetcher, analyser, and visualiser; (3) Live flood impact quantifier that computes the following measures in near real-time; number of flood affected buildings, and flooded land area expressed in square kilometres.

### 4.4 IoT Sensor Derived Insights from Key Indicators

It can be seen how IoT sensor data can be effectively integrated into an open-source architecture to enable near real-time responsive flood event representation (RQ1). A live data feed delivered via an Application Programming Interface (API) is harnessed by the application, upon which data analytics are performed and insights are derived. Inclusion of an open API would ensure the web application further aligns with the concept of open-source accessibility; however, the Melbourne Water API provides an authoritative source suitable for the purposes of this project.

It was found that the key indicators of near real-time rainfall and river height data were able to effectively inform the digital representation of flood extents (RQ2). Use of these two particular indicators provides an approximation of the study area, however, advancements could be made in the calculation of the flood buffer extents. The Melbourne Water API records rainfall in four different categories; rainfall since 9am, for the last 24 hours, for the last 7 days, and for the last 30 days. The web application uses the last 24 hours reading in tandem with current river height to compute the flood extent buffer, however the other three categories could also be incorporated in future iterations. The rainfall since 9am reading is the closest to a near real-time data stream however limitations are still present depending on what time the user accesses the web application and fetches data. Despite the latter two categories are not near real-time, these additional historical records could be used to further refine the flood buffer and thus enhance overall accuracy of the flood representation. Furthermore, as a hydrological flood model, the current implementation is quite primitive. By harnessing river height data from outside the study area, particularly in upstream regions of the Maribyrnong River, more informed representations of flood events would become possible. Opportunity also exists for coupling the web application with more advanced hydrological models; however, this approach would need to maintain the core concepts of live data and an open-source framework.

Quantifying impacts of flood events in near real-time is achieved through a combination of IoT sensor data fetched via API and server-side processing in the JavaScript source index file (RQ3). The JavaScript library Turf.js is fundamental for manipulating the live data into meaningful results. In this way, it can be seen how analysis rooted in geospatial theory can contribute towards informed decision making.

### 4.5 Limitations

While the architecture shows promise, it is important to acknowledge its proof of concept development. Open access availability to data presents a critical limitation, restricting the scope of this project. Although sufficient open source data was accumulated for the project's study area, it becomes evident that in other study areas where such data is lacking, the implementation of Digital Twin technology becomes challenging. This limitation highlights a noteworthy barrier to widespread industry adoption, underscoring the nascent state of Digital Twin technology. Further complications arise due to the high volume of data required, as well as the necessity for effective management within a single federated data model to ensure interoperability, further enhance these limitations.

Moreover, the utilization of various data formats, such as CityGML, GeoJSON, GeoTIFF, and Shapefile, stored in two separate databases, contributes to the complexity of a Digital Twin. However, the use of Cesium ion to consolidate all the data into a single source proves sufficient for this project, enabling seamless importation, manipulation, and visualization in the Webpack JavaScript application. While these limitations are notable, they serve as indicators of an evolving field with immense potential. The early stage nature of the web application’s development emphasizes that strides are being made towards overcoming these challenges. As advancements continue, the impact and contributions of Digital Twin technology in various industries remain highly promising.

### 4.6 Opportunities for Future Research

Despite the existing barriers to the broader implementation of Digital Twin technology, there are ample opportunities for advancing the current web application’s capabilities. The incorporation of the following features together hold potential to enhance the web application in terms of automated database connectivity, more accurate depiction of reality, enhanced flood representation precision, and therefore more precise data analytics:

a. Allow for automated and seamless updates to the spatial basemap, integrated database connectivity to Cesium ion can be achieved using a third-party REST API as outlined by Diakite et al. (2022);
b. High resolution LiDAR for substantially more accurate terrain representation (Wilson et al., 2022). This would enable more precise estimations of flood extents and also allow for a total flood water volume computation using a cut-and-fill function;
c. Land use classification attributed with permeability data would enable the computation of water absorption rates,

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thus better informing flood water height and extents (Shen et al., 2020);

d. Storm water drainage network data would allow the integration of flood water runoff and rates of water dissipation during flood events (Shen et al., 2020);
e. Infrastructure models such as roads and bridges for more detailed representations of reality and associated flood impacts (Langenheim et al., 2022). This could also provide a means to assist emergency response efforts in identifying the safest land route of access or escape from a flooded area;
f. Higher level of detail (LOD) CityGML format models for enhanced immersion;
g. Socio-economic data to inform levels of vulnerability and economic impacts of flood events. Low lying areas and proximity to water bodies combined with this could be used to develop a flood disaster recoverability score. In terms of economic impact, a flood insurance claim estimator based on the number of floods affected properties could also be devised.

## 5. Conclusion

In a world where both urbanisation and the effects of climate change are simultaneously amplifying, digital tools to help manage associated hazards are necessary. Flash flooding poses an especially significant threat to rapidly expanding and densifying urban areas. It can be seen how Digital Twin technology is well positioned to respond to this threat through accumulation of various open source technologies. This project has developed a replicable open source framework for near real time responsive flood event representation in an interactive web application. The results of this project aim to promote this technology for further widespread use through demonstration of Digital Twin based technology’s potential for the application of responsive flood event representation through integration of near real time data analytics. Consideration of end user accessibility also results in an application that visualises flood extents in an easily interpretable way.

Furthermore, the provision of flood impacts as derived statistics equips decision makers with swift, actionable insights during disaster events. This holistic approach, from technological development to user friendly application, underscores the transformative potential of Digital Twin based technology in revolutionising flood management practices.

In conclusion, this project not only advances the field of interactive and near real time flood event representation but also heralds a new era in disaster resilience. By bridging the gap between technological innovation and practical application, it paves the way for a future where cities are better equipped to navigate the challenges posed by steadily increasing rates of urbanisation and the ever present impacts of climate change.

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