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Flood Resilience Digital Twin (FReD): Empowering decision makers for improved management of flood risk

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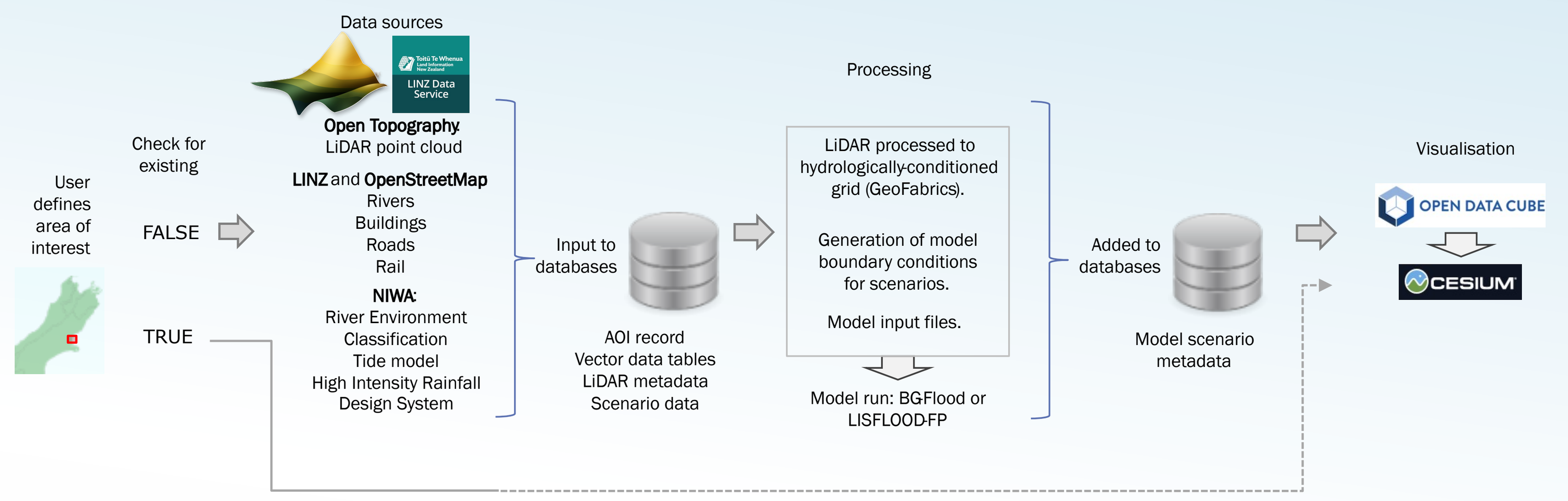
Flood inundation is a frequent, widespread, and impactful hazard, which regularly causes damage to housing and infrastructure along with disruption to communities and businesses. Further, flood risk is expected to increase in future, due to increased storminess caused by climate change, and rapid urbanisation. To manage this risk, it is essential that we become more efficient at flood risk management. We need to improve land use planning to take account of multiple scenarios for potential flood impact or mitigation. However, the computational modelling and scenario assessment required for such flood risk management and mitigation requires substantial amounts of spatial data related to infrastructure and the environment, making it challenging and expensive. This is a particular problem for smaller regions or communities where the costs of such analysis may be prohibitive. Environmental digital twins can solve this challenge by enabling automated data capture and rapid processing of large volumes of disparate geospatial data. When combined with automated data analytics, this can break down barriers which exist for decision making due to the significant expertise and resources required to process, join, and analyse data. In this presentation, we share our prototype Flood Resilience Digital Twin (FReD). This open-source system automates the ingestion and processing of the varied data needed for flood risk assessment, runs a computational flood model to assess multiple scenarios, then ingests and analyses the results enabling potential flood impacts to be assessed. This is integrated with a web-based interface and 3D visualisation tool, which provides a powerful front-end to access the digital twin. Once complete, the system will enable decision makers to obtain flood impact assessments on demand, for existing or new flood hazard scenarios, during events or as part of planning scenarios.

LINZ air photos in the aftermath of cyclone Gabrielle, acquired 19-20 February 2023

Background

Over the last few years, the development of digital twins has accelerated greatly, especially within the manufacturing industry (Jones et al., 2020; Semeraro et al., 2021). Numerous definitions of the concept of a digital twin exist, with definitions tending to vary depending on the field (Fuller et al., 2020); in general terms, a digital twin is a dynamic virtual representation of a physical system (e.g., Madni et al., 2019), with automated data exchange being a key attribute. Digital twins are enabling the development of the next generation of smart cities (Deren et al., 2021); more recently, the concept has expanded to include digital twins of the natural environment (Blair, 2021) and there is, for example, significant investment by the European Union (EU) towards the creation of a digital twin of Earth, with the aim of ensuring climate neutrality by 2050 (Bauer et al., 2021). The EU's "Destination Earth" (DestinE) policy brings together computation and data lakes to create a "seamless fusion of real-time observations and high resolution predictive modelling" for critical application areas including extreme events and climate change adaptation (European Commission, 2022).

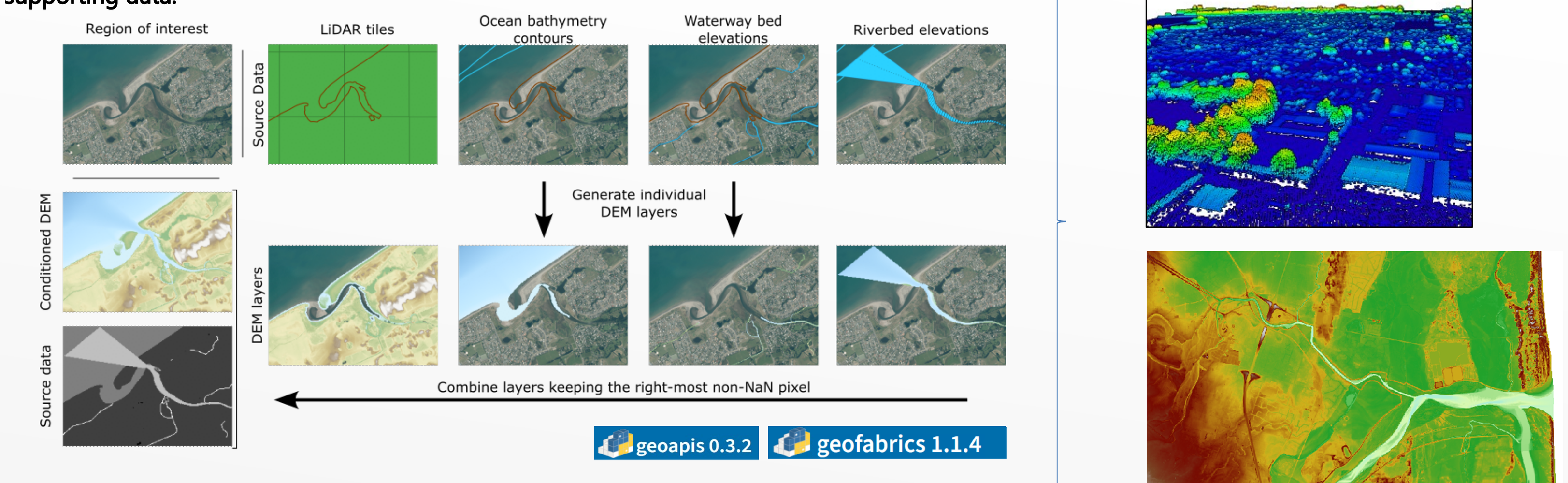
1. Current pipeline overview



Fully open-source code! Check it out here: https://github.com/GeospatialResearch/Digital-Twins
End-to-end integration branch = dt-pre-release-candidate

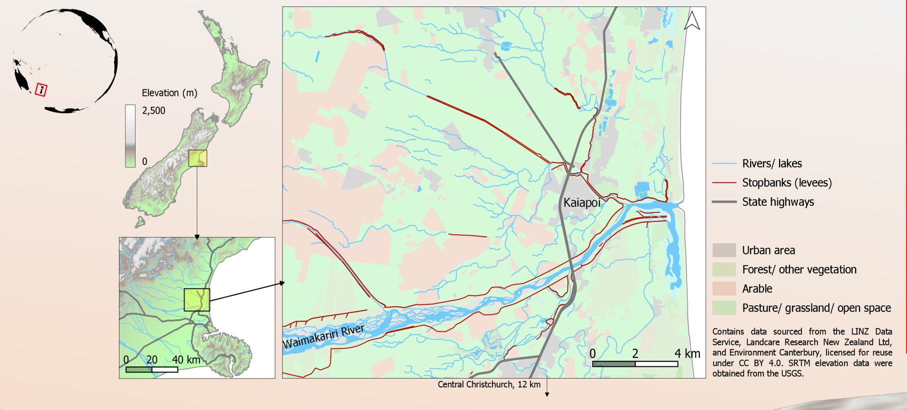
2. Generation of model input data

Automated production of "hydraulically conditioned" model grid from LiDAR point cloud and supporting data.



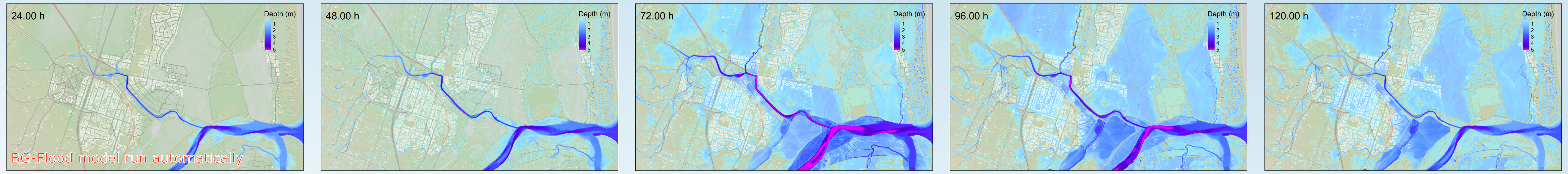
Geofabric generation is a multistage process for creating hydrologically conditioned DEMs from a range of programmatically accessed LINZ data (Pearson et al. 2023).

Prototype development site: Kaiapoi

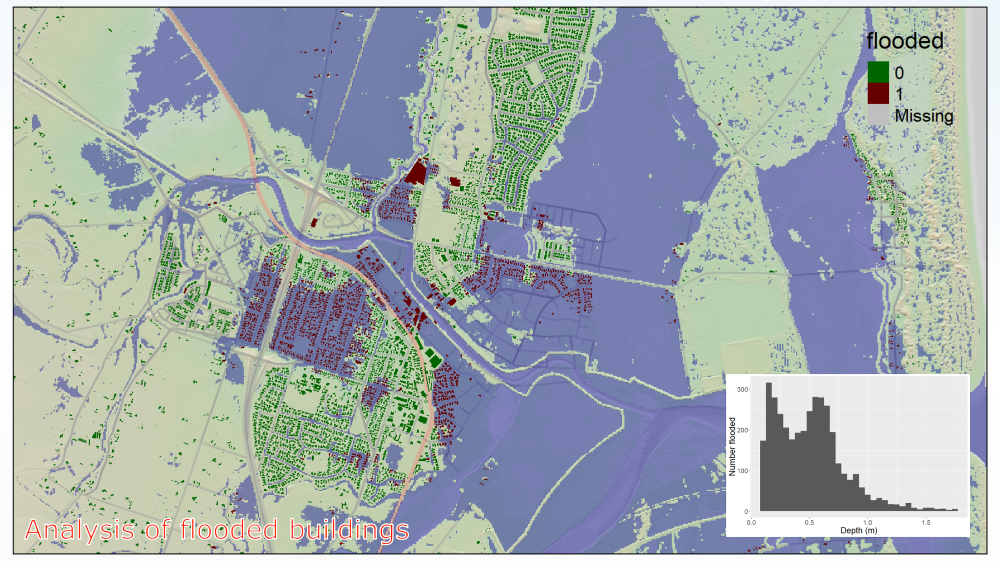


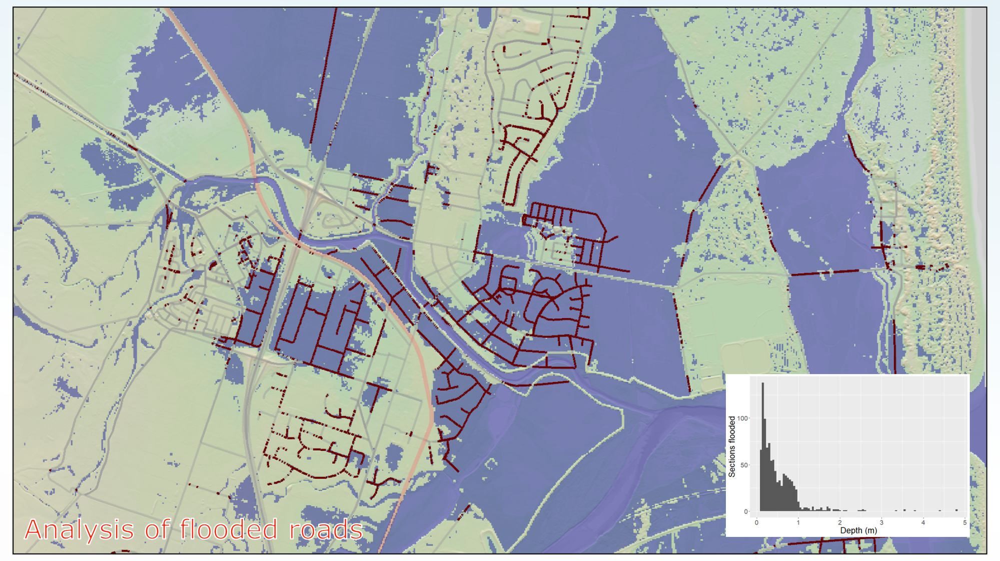
After download and incorporation into local databases (box 1), data are further processed within the digital twin to create the "GeoFabric" (box 2), which refers to the model inputs and boundary conditions, including the scenarios assessed, in the appropriate model format (in this case, BG-Flood). Dynamic boundary condition data are obtained which represent flows into the domain and a downstream tide level (box 3). Rainfall and river flow input data are derived statistically from existing databases which have been generated based on historical observations. For the tide level, by default the annual maximum high tide for the last year is obtained. To account for sea level rise in the scenarios, differing levels of sea level can be included on top of the tide level. Climate scenarios can be included in both the rainfall and the sea level. The model is then run (4), and the digital twin maintains metadata regarding simulations. Finally, model results are incorporated back into the digital twin for analysis, such as identifying flooded buildings (5), and comparison of different scenarios (6). To complement the data processing and computational engine, which forms the foundation of the digital twin, we have developed a web-based visualisation environment based on the Cesium open platform for 3D geospatial data (7).

4. Scenario simulation

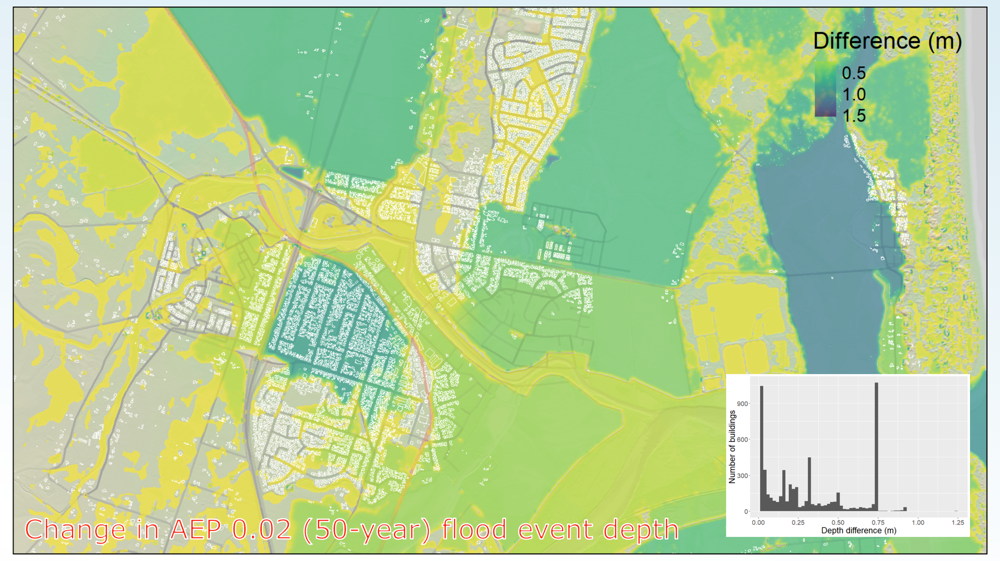


5. Scenario analysis

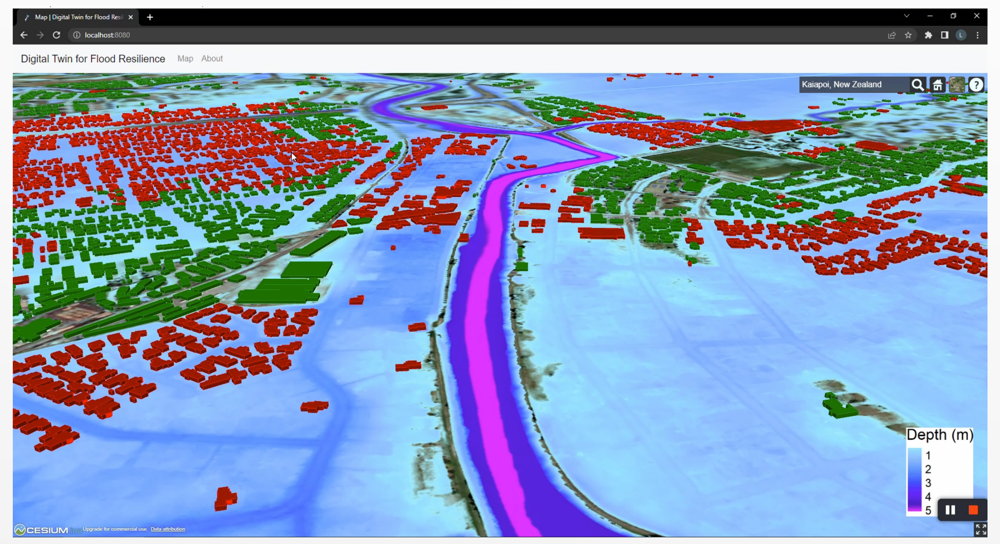


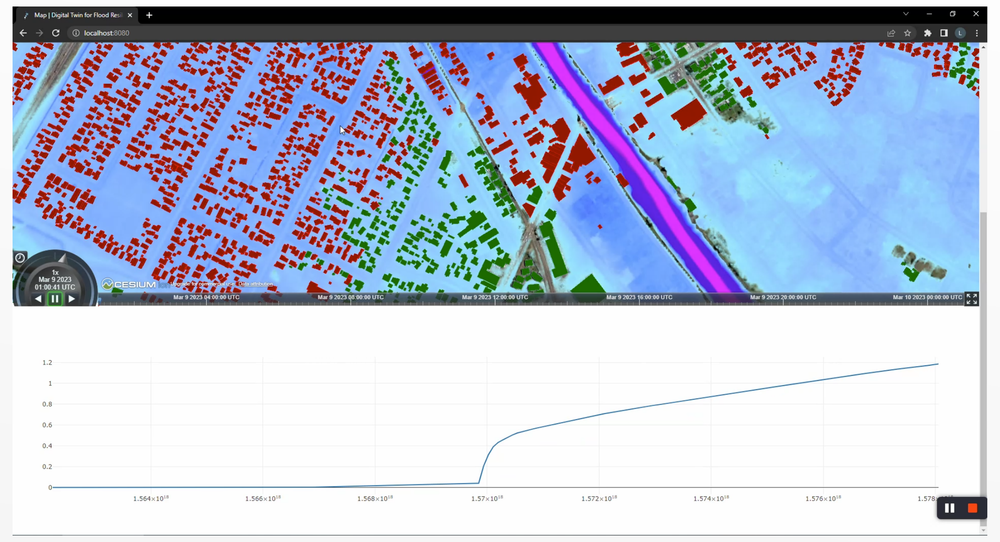


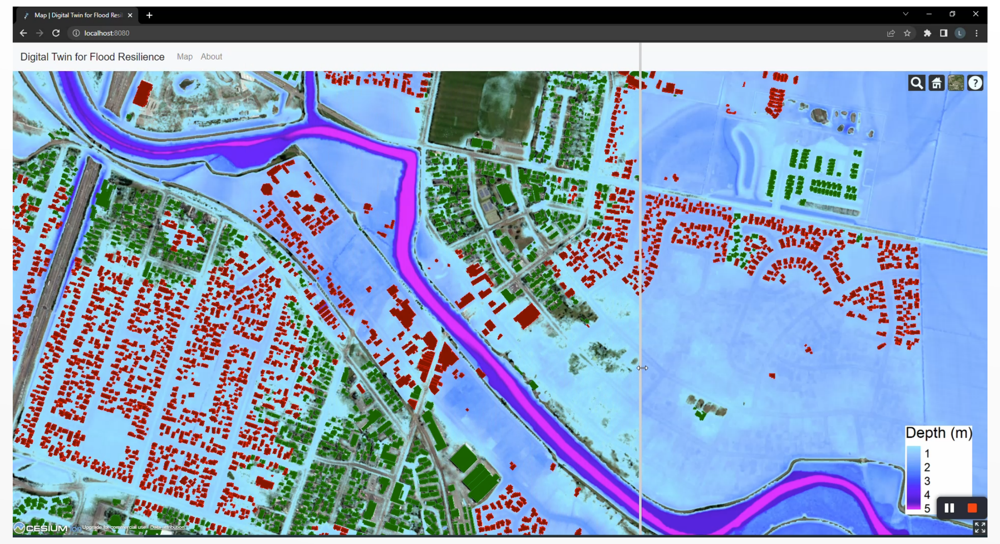
6. Scenario comparisons



7. 3D Visualisation







The focus our work was to build an environmental digital twin which brings together computational models of flood inundation with other data, for hazard assessment, management, and mitigation. A key objective was to enable the automation of flood risk assessment, such that multiple scenarios can be assessed rapidly, such as when given updated information. The fundamental design principle was that the digital twin should broadly adopt the "Findable, Accessible, Interoperable and Reusable" (FAIR) principles, and be open, extendable, interoperable, replicable, dynamic, versatile and scalable. Research was underpinned by methods developed in an aligned research programme, Mā te haumaru ō te wai, led by NIWA, which is assessing flood risk across New Zealand. Future work will include additions to the backend functionality such as additional scenarios, connections to additional data, development of a storm drainage module, integration of machine learning methods, and a connection to RiskScape. For the frontend, an improved user interface will be developed alongside dynamic and immersive visualisations. Finally, we will develop a hosted digital twin solution and seek to scale across New Zealand and, longer term, internationally.

References

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Source code available under open-source licensing!
https://github.com/GeospatialResearch/Digital-Twins

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