FlashFloodBreaker: Transforming emergency response through immersive reality and geospatial modelling

The University of Luxembourg is leveraging drone photogrammetry, AR/VR simulation, and serious gaming to transform flash flood preparedness across Northwest Europe

NORTHWEST EUROPE (NWE) is facing an increasing frequency and severity of extreme flash flood disaster events. Driven by climate change, sudden high-energy flood events triggered by intense, short-duration rainfall over small catchments leave residents and emergency responders with minimal warning time. The tragic events of July 2021, which caused widespread devastation and fatalities across Germany, Belgium, the Netherlands, and Luxembourg, laid bare this region's vulnerabilities. Unpredictable, rapid water level rises, high flow velocities, and cascading infrastructure failures overwhelmed early warning systems and caught populations off guard.

To address this pressing challenge, the Interreg Northwest Europe programme has funded the FlashFloodBreaker project (2024 to 2028). An ambitious transnational initiative encompassing 13 partners from six countries, FlashFloodBreaker works to empower organisations responsible for flood management and residents in risk-affected areas, as well as scientists. The initiative is pioneering a joint strategy for effective flash flood risk management, advancing real-time prediction models, providing joint training schemes, and formulating six jointly piloted solutions spanning crisis unit preparation to on-the-ground rescue capabilities.

As a core scientific partner in this consortium, researchers from the GGE within the Faculty of Science, Technology and Medicine (FSTM) at the University of Luxembourg are translating high-fidelity geomatics research into actionable, life-saving awareness. Specifically, the GGE team is tackling the critical human element of disaster response by training residents and responders to make split-second decisions under extreme pressure using cutting-edge Augmented Reality (AR), Virtual Reality (VR), and immersive training applications, driven by high-resolution multi-source geospatial data.

Bridging the behavioural gap through immersive realism

Despite immense progress in meteorological forecasting and hydrodynamic modelling, human behaviour remains a critical vulnerability during sudden onset of floods. Traditional tabletop drills and community exercises operate under static, scripted conditions. They invariably fail to replicate the true cognitive stress, reduced visibility, environmental noise, and physical urgency inherent to a flash flood crisis.

To address this training gap, the FSTM team is building a fully adaptive immersive flash flood simulation. By

recreating the sensory and psychological conditions of a flood event (turbidity, rapidly rising levels, debris accumulation, shifting weather, and infrastructure failures), the VR/AR platform allows users to experience the onset of a disaster in a controlled, repeatable environment. The objective is to evaluate behavioural thresholds, improve intuitive decision-making speed, and mitigate the risk normalisation and delayed evacuation responses frequently observed in recent disasters.

Mapping the threat: Drone flights, LiDAR, and 3D reality

The foundation of the immersive environment lies in geometric accuracy. To ensure that the VR/AR simulations are visually and scientifically faithful to real-world hydrometeorological conditions, our team integrates multi-source terrestrial and aerial geospatial datasets.

Utilising Unmanned Aerial Vehicles (UAVs) equipped with multispectral, RGB cameras, and mobile or terrestrial LiDAR platforms, the team has conducted exhaustive data collection missions across highly vulnerable sites in Luxembourg, such as the communes Mersch, Walferdange, and Lintgen. Through advanced photogrammetry, specifically employing Structure from Motion (SfM) techniques and state-of-the-art 3D Gaussian Splatting, the GGE team is reconstructing these environments with centimetric precision.

As outlined in the project proposal, the GGE is playing a central role in drone-related activities by setting up a joint platform for real-time processing of data collected by drones flying in distinct regions across the network. These dense 3D point clouds and surface models are safely imported into our XR (Extended Reality) environment engines. We correlate our photogrammetric mapping of dry baseline conditions against data captured during active flood events to construct highly accurate, hyper-realistic Digital Twins. When layered with hydrodynamic models and sensor inputs (such as rapid water level elevations from hydrometric gauges), the VR simulations present citizens and emergency services with a localised, familiar, and highly reactive visualisation of exactly how a flash flood would unfold in their own neighbourhoods.

The flash flood escape game co-designing with stakeholders

Grounding technological innovation in real-world psychology is crucial. The strongest innovation of our work remains its grounding in the general public and responder experience rather than arbitrary developer assumptions.

Recognising that behavioural mapping must be survivor-informed, our team developed the Flash Flood Escape Game, a collaborative scenario co-design exercise. Debuted and tested during the recent FlashFloodBreaker Project Working Group (PWG6) meeting in Cork in March 2026, the game proved to be an incredibly effective, low-cost instrument for capturing genuine behavioural responses under simulated time pressure.

During the interactive sessions, consortium partners, hydrologists, civil protection experts, and operational end users played the role of participants. Drawing hazard scenarios directly onto the Mersch Park blueprint, stakeholders proposed concrete new risk parameters, including progressive water level thresholds, road blockages, and debris-triggered secondary hazards. The genuine decision-making data and interactive blueprints generated during this tabletop game are directly informing the next iteration of the digital flood scenarios, driving the hazard logic within our AR/VR and immersive reality prototypes. Moving forward, the game will be translated into multiple languages and comprehensively tested with different demographic categories, ranging from students to local communities.

Towards resident empowerment and rescue capabilities

Moving forward, the GGE team is preparing the rollout of our immersive toolbox and is actively driving the development of these immersive technologies for enhancing awareness amongst residents. With pilot tests underway with emergency response professionals, primarily the Moselle departmental fire and rescue service (SDIS57), the team collaborates closely with project partners to develop scenarios for training the residents with the help of transnational emergency response teams.

By equipping laypeople with the experiential knowledge of navigating sensory overload and dynamic water hazards safely, FlashFloodBreaker seeks to dramatically reduce vulnerabilities in northwest Europe. Additionally, the SerVal research group from the Interdisciplinary Centre for Security, Reliability and Trust (SnT) at the University contributes key expertise in artificial intelligence (AI) and Machine Learning (ML), ensuring that real-time forecasting models remain trustworthy, transparent, and explainable to end users and flood risk managers.

A hybrid VR/AR approach is the project's optimal design choice. While VR offers completely controlled, emotionally engaging photorealistic immersion for behavioural testing, AR delivers real-world contextual overlays for field training, public engagement, and post-event analysis. Together, these tools merge geomatics, cognitive science, hydrology, and artificial intelligence into a transnational resilience strategy.

The University of Luxembourg offers

The Faculty of Science, Technology and Medicine proudly contributes to building a stronger, safer region, offering comprehensive capabilities across geodetic and geospatial sectors:

- Immersive Disaster Preparedness Capabilities
  End-to-end development of XR (VR/AR) immersive environments for civil protection, emergency response training, and citizen awareness campaigns.
- High Resolution 3D Surveying and Reality Capture
  Expertise in UAV-based photogrammetry, terrestrial and mobile LiDAR, and multispectral imaging for environmental, structural, and topographic mapping.
- Geospatial Data Processing: Robust integration of 3D reconstruction (Gaussian Splatting, SfM) with real-time sensor networks and hydrodynamic simulations.
- Consultancy and Behavioural Analysis Scenario co-design methodology (such as serious gaming) to evaluate cognitive load, decision making, and situational awareness in critical environments.

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