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Digital Twin for Nature-Based Solutions: Case Studies on River Improvement and Ecological Restoration Integrating Flood Control, Landscape, and Environment

Jumelles numériques pour des solutions basées sur la nature : Études de cas sur l'amélioration des cours d'eau et la restauration écologique intégrant la lutte contre les inondations, le paysage et l'environnement

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RÉSUMÉ

La gestion des rivières au Japon a évolué pour équilibrer le contrôle des inondations avec des objectifs environnementaux, comme en témoigne la révision de la Loi sur les rivières en 1997 et l'adoption en 2006 de la gestion orientée vers la nature. Le changement climatique a intensifié les inondations, conduisant au concept de "Résilience et durabilité des bassins versants par tous" en 2020, qui met l'accent sur la collaboration entre les parties prenantes. L'intégration de solutions fondées sur la nature (NbS), telles que les infrastructures vertes et la restauration écologique, dans ce cadre reste un défi crucial. Les avancées technologiques, comme la modélisation 3D, la bathymétrie laser aéroportée (ALB) et les jumeaux numériques, ont permis de simuler des environnements réels pour l'analyse de scénarios et la prise de décision. Les moteurs de jeu, tels qu'Unreal Engine, renforcent ces capacités grâce à des outils de visualisation avancés, favorisant l'engagement public et la sensibilisation aux NbS. Les prototypes intégrant des données hydrologiques et écologiques démontrent l'efficacité des NbS dans le contrôle des inondations et la restauration des habitats, mettant en lumière des avantages tels que l'amélioration de la biodiversité et des paysages durables. Malgré les défis liés à la modélisation de systèmes complexes, à la gestion de grands ensembles de données et à l'intégration précoce des NbS dans la planification, l'intégration des jumeaux numériques, des moteurs de jeu et des NbS offre une voie transformative vers une gestion des rivières résiliente et durable.

ABSTRACT

Japan’s river management has evolved to balance flood control with environmental goals, exemplified by the 1997 River Law revision and the 2006 adoption of Nature-oriented River Management. Climate change has intensified flooding, leading to the 2020 "River Basin Disaster Resilience and Sustainability by All" concept, which emphasizes collaboration among stakeholders. Incorporating nature-based solutions (NbS), such as green infrastructure and ecological restoration, into this framework remains a critical challenge. Advances in technologies like 3D modeling, airborne laser bathymetry (ALB), and digital twins have enabled the simulation of real-world environments for scenario analysis and decision-making. Game engines like Unreal Engine enhance these capabilities with advanced visualization tools, promoting public engagement and awareness of NbS. Prototypes integrating hydrological and ecological data demonstrate the effectiveness of NbS in flood control and habitat restoration, highlighting benefits such as biodiversity enhancement and sustainable landscapes. Despite challenges in modeling complex systems, managing large datasets, and embedding NbS early in planning, the integration of digital twins, game engines, and NbS offers a transformative pathway to resilient and sustainable river management.

KEYWORDS

Digital Twin, Game Engine, Flood Control, Nature Restoration, Visualization

Contrôle des inondations, Restauration de la nature, Visualisation

1 INTRODUCTION

Efforts to restore nature in Japan's rivers began in earnest around 1990s. A major milestone was the 1997 revision of the River Law, which expanded its objectives to include environmental considerations alongside flood control and water supply. By 2006, Nature-oriented River Management was implemented across all river systems in Japan. However, climate change has intensified flooding, shifting the focus of river management back toward flood control. In 2020, the "River Basin Disaster Resilience and Sustainability by All" concept was introduced, emphasizing collaboration among all stakeholders in a river basin. Alongside large-scale disaster prevention initiatives efforts are being made to integrate policies that harmonize with nature, such as green infrastructure and Nature-Positive initiative. Achieving a balance between flood control and ecological preservation remains a pressing need.

On the other hand, rapid advancements in technology are offering new solutions. The shift to 3D technologies, such as point cloud surveying, has transformed the field. Airborne laser bathymetry (ALB), used to estimate river depths, has been standard technology in Japan since 2017. Additionally, data openness is increasing, with initiatives like the PLATEAU project (https://www.mlit.go.jp/plateau/) from 2021 promoting sharing of 3D urban models. Hydrological tools like iRIC software (https://i-ric.org/) and RRI (https://www.pwri.go.jp/icharm/research/rri/index.html) are also widely used for flood analysis. Regarding visualization, game engine software suite is capable to offer a realistic scene of 3D world. These advancements are paving the way for digital twins in river management.

A digital twin is a virtual 3D model of the real world. In the current situation, digital twins should be purpose-built and require a clear understanding of user needs. In river management, stakeholders - including government agencies, residents and engineers - need tailored information. Accessibility and ease of use are essential for widespread adoption, requiring simple, practical tools and workflows. In this presentation, we provide a practical example of how to create a digital twin for NbS and its effectiveness.

1.1 What is a Game Engine?

Digital twins require effective visualization to maximize their utility. Game engine is a software suite initially developed for video games, offering advanced 3D rendering and simulation capabilities. These tools enable immersive experiences, allowing stakeholders to better understand and interact with complex data. Game engines also facilitate collaborative and participatory design in public works, breaking down traditional barriers. It is becoming clear that this is a powerful tool that can be used to address the multiple directions of river and catchment development at the same time (Yin et al., 2024).

1.2 Practical Use in Japan

The Kyushu Regional Development Bureau pioneered the use of Unreal Engine in river management in 2021, employing it to design the Yamakuni River waterfront. The project resulted in freely available tools, such as DEM converters and native plant digital assets, simplifying the adoption of game engines in similar projects (https://www.qsr.mlit.go.jp/infradx/indexge.html).

2 APPLICATION TO RIVER IMPROVEMENT

2.1 Landscapes

A digital twin prototype (Figure 1) for river improvement incorporated:

- DEMs and aerial images from aerial laser profilers.
- Distant landscape visualized by importing from Cesium ion 3D map platform
- 3D assets of structure and symbolic vegetation like cherry blossoms from marketplace.
- UAV-derived models for buildings and hedges.

2.2 Flow Visualization

Two methods were used:

- HAP (Hydraulic Analysis Pipeline) Plugin: Converts hydraulic analysis results by iRIC Software into visualized flows with adjustable ripples for accuracy in flood simulations. Participants in the Digital River Research Forum (https://www.facebook.com/100088105993529/) can receive the beta version if they wish.
- FluidFlux Plugin: Simulates shallow water dynamics partially combined with computational particle

method under the Unreal Engine software, offering high-quality visuals with realistic effects like bubbles and sound.

2.3 Effectiveness of Visualization

Interviews with administrators revealed that game engines bridge communication gaps with residents and that they need training to use them effectively. They are also concerned that a realistic representation of risk could lead to miscommunication with people.

Public surveys showed significant improvements in understanding of flood risks, infrastructure functions and landscapes, with younger participants valuing infrastructure insights and older participants focusing on environmental awareness.

Figure 1. Digital twin for river improvement built with a game engine (Unreal engine) a) Usual situation, b) Flood time under current condition and c) under the post countermeasure condition.

3 CHALLENGES IN NATURE RESTORATION USING DIGITAL TWINS

Three issues can be raised below:

- Representing Natural Objects: Accurate 3D modeling of natural elements like trees requires to use tools (like UAV and TLS) correctly to manage amount of data. Large datasets efficiently remain a technical challenge.
- Sharing Knowledge: Promoting game engines among engineers require skill-sharing and accessible tools. Forums and competitions are fostering technical knowledge and innovation in Japan.
- Market Development: Visualization tools must be integrated early in the planning process to enhance productivity, but current practices limit their use to final stages.

4 CONCLUSION

The game engine-powered digital twins can contribute river management along nature-based solutions (NbS) by combining advanced visualization, real-time data analysis, and collaborative tools. Digital twins enable precise modeling and scenario testing, while game engines enhance stakeholder engagement through immersive experiences. NbS, such as green infrastructure and ecological restoration, provide sustainable solutions for flood mitigation and biodiversity enhancement. However, challenges in representing natural systems, handling data, and early integration persist. Addressing these requires skill development, accessible tools, and knowledge sharing. Case studies demonstrate these technologies' potential to improve communication, public understanding, and participatory design, driving resilient and sustainable river management. In addition to visualization, prediction of the future of riverbeds and the environment using 3D topographical datais also essential to achieving NbS.

LIST OF REFERENCES

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