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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1.Introduction

- This presentation provides a practical example of **how to implement a digital twin for NbS using open data and game engine** and evaluate its effectiveness.
- Efforts to restore nature in Japan's rivers.
  - In 1997, the **revision of River Law** was done to include environmental considerations.
  - In 2006, **nature-oriented river management** was implemented across all river systems in Japan.
  - In 2020, the "**River Basin Disaster Resilience and Sustainability by All**" concept was introduced in response to the need for climate change adaptation, emphasizing collaboration among all stakeholders in a river basin.
- Progress in 3D technologies.
  - In 2019, **Airborne laser bathymetry (ALB)** has been the standard.
  - In 2021, we had our first experience with **public works using game engine** software.

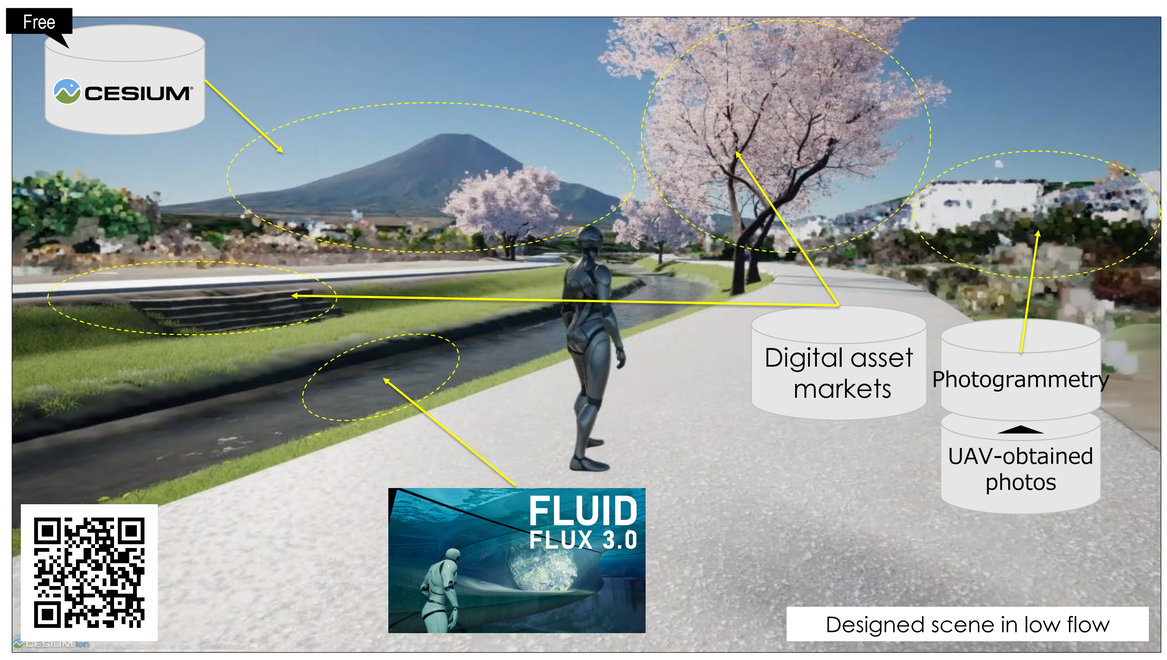
NbS digital twins that integrate flood control, landscape, and the environment are expected to play an important role near future.

Aims and Steps

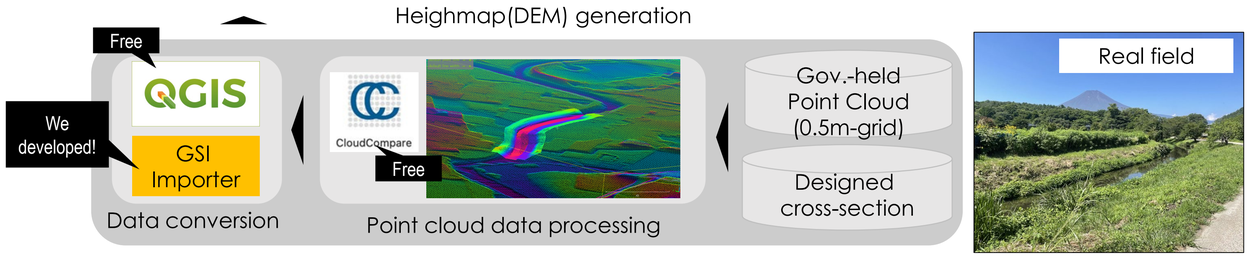
- **Proposing methods for creating cost-effective, regionally-tailored NbS digital twin.**
- **Appling the method to river engineering and ecological restoration field.**
- **Investigate the effectiveness of NbS digital twins for each stakeholder.**

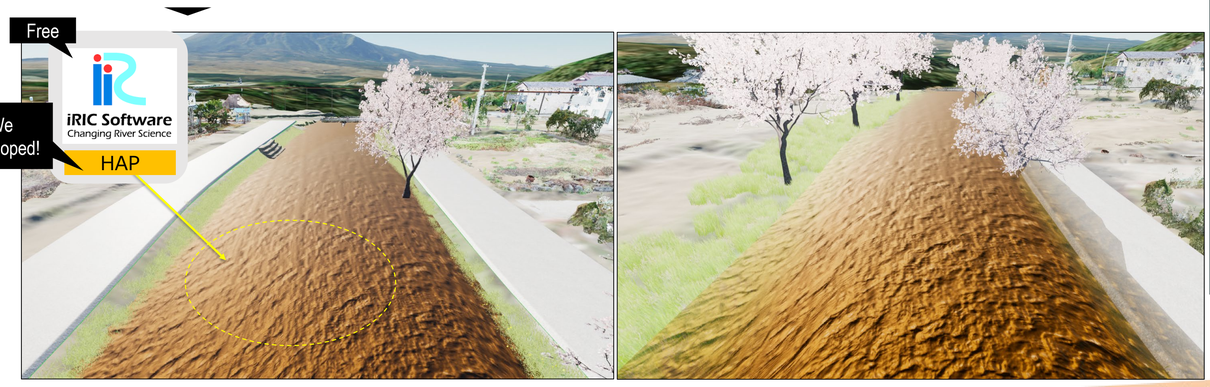
2. Modeling method

- Game Engine
  - Game engine is a software suite for video games development, offering advanced 3D rendering and simulation capabilities.
  - These tools enable immersive experiences, allowing stakeholders to better understand and interact with complex data, enhancing collaborative and participatory design in public works.
- Landscapes
  - LiDAR-based DEM and planned cross-sec. data from **Local gov.**.
  - Distant landscape visualized from **Cesium ion**
  - Cherry blossoms from **3D assets marketplace**.
  - **UAV-derived models** for buildings and hedges.
- Flow Visualization
  - **FluidFlux UE Plugin** offers high-quality visuals with realistic effects based on physical simlutaion .
  - **HAP (Hydraulic Analysis Pipeline) UE Plugin** we built can convert hydraulic analysis results by iRIC Software into visualized flows with adjustable ripples for accuracy in flood simulations.



Heighmap(DEM) generation





Designed condition scene in high flow

Current condition scene in high flow

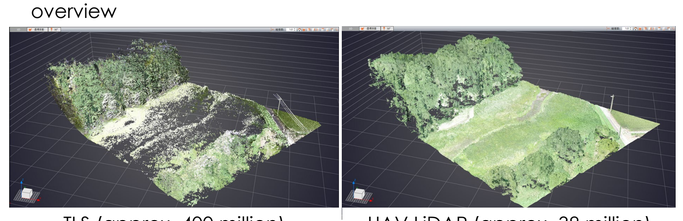
3. Technical Issues

- Technical Issues
  - To make people feel natural restoration positively, it is necessary to model nature objects appropriately.
  - We conducted UAV LiDAR and TLS measuremearches, and we compared the results in terms of detection points and point cloud density.
  - 3D modeling of natural object requires to use tools correctly.
  - Slow rendering detracts from nts targeting the comfort tree immersion.

tree arch

TLS (approx. 400 million) UAV LiDAR (approx. 38 million)

overview



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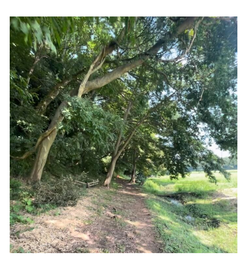


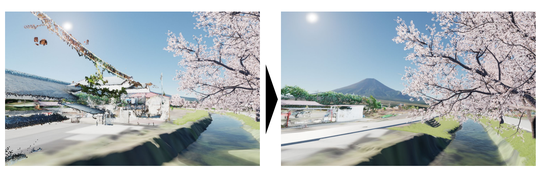
Target tree arches

Point density reduced by half (200 million points)

Point density is reduced to a quarter (100 million points)

4. Effectiveness of Visualization

- Interviews with administrators
  - They believe game engines can bridge communication gaps with residents, but residents need training to use them effectively.
  - However, they are concerned that a realistic representation of risk could lead to miscommunication.
  - They all found the visualization of landscape changes useful. It has the potential to inspire ideas from citizens and encourage their participation. Since residents' interests vary, thorough prior consultations are important.



The relocation of the house will make Mount Fuji visible.

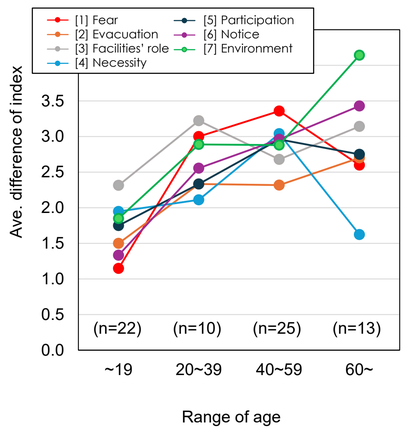
- Public surveys
  - We had citizens experience VR at community exchange events and school festivals. We then scored how their experiences differed from previous explanations.
  - Questions regarding the quality of digital twins

    ("best, no discomfort" = 5, "poor, discomfort" = 1)

Result of evaluation for quality of digital twins

Element	Modeling	Value	Improvement
Whole	—	4.18	Audio guide
Terrain	LP-based dem	4.26	-
Building	UAV	3.79	-
Structure	3D mesh	4.07	-
Trees	3D mesh	4.26	-
Distant view	Cesium	4.39	-
Flooding	iRIC+HAP	4.19	Sound of flow
Low flow	FluidFlux	4.47	—
Action of avatar	—	4.18	Avatar drowning
VR sick	Third person	4.66	—

  - Questions regarding the effectiveness of digital twins ("Most applicable" = 10, "Not" = 1)
    - [1] **Fear**: I felt a sense of urgency and fear about flooding.
    - [2] **Evacuation**: I knew what to do when there's a flood.
    - [3] **Facilities' role**: I understood how the facilities work.
    - [4] **Necessity**: I understood that we needed to control flooding.
    - [5] **Participation**: I believe residents can help with public works.
    - [6] **Notice**: I noticed additional actions to improve.
    - [7] **Environment**: I felt importance of landscape and environment.
  - Significant improvements in understanding of flood risks, infrastructure functions and landscapes.
  - Younger participants valuing **[3] Facilities' role** and older participants focusing on **[7] Environment** .



Result of evaluation for quality of digital twins

5. CONCLUSIONS

- 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 details also essential to achieving NbS.