Simulating Robots Activities and Humans Experiences in Underwater Environment

UNIVERSITÀ DELLA CALABRIA
DIPARTIMENTO DI INGEGNERIA MECCANICA, ENERGETICA E GESTIONALE
DIMEG

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3D RESEARCH

www.3dresearch.it

Prof. Fabio Bruno

SIMULTECH 2023
13th International Conference on Simulation and Modeling Methodologies, Technologies and Applications
Rome, Italy 12 - 14 July, 2023

Presentation

UNIVERSITÀ DELLA CALABRIA

- 13 Departments
- 900 Professors and Researchers
- 750 technical and administrative staff
- 30.000 students

SPINOFF › UNIVERSITÀ DELLA CALABRIA

AppliCon

Underwater communication and localization

3D RESEARCH EXPERIENCE TECHNOLOGY

Underwater 3D and Augmented Reality

tech4sea underwater technologies

Underwater mechatronics

Preservation and Dissemination of Underwater Cultural and Natural Heritage

European Projects and Partners

- **iMARECulture** (Immersive Serious Games and augmented reality as tools to raise awareness and access to european underwater culture) - H2020- SC6-CULT-COOP-2016-2017
- **Lab4Dive** (Mobile smart lab for augmented archaeological dives) - EASME/EMFF/2016/1.2.1.4 “BLUE-LABS”
- **DiveSafe** (Integrated system for scientific and environmental underwater surveys, with advanced health & safety features) - EASME/EMFF/2017/1.2.1.12 – Sustainable Blue Economy
- **MeDryDive** (Creating personalized dry drive experiences for the promotion of Mediterranean Underwater Cultural Heritage sites as distinctive tourism destinations) - COSME ICOS-TOURSYN-2018-3-01
- **MAREBOX** (Culture underwater. Time capsules at the bottom of the sea) - CREATIVE EUROPE – CROSS- SECTORAL STRAND – BRIDGING CULTURE AND AUDIOVISUAL CONTENT THROUGH DIGITAL
- **TecTonic** (TEchnological Consortium TO develop sustaiNabIlity of underwater Cultural heritage) - H2020-MSCA-RISE- 2019
- **CREAMARE** (Linking creativity, culture and media technologies in the transnational co-production of digital interactive products for the communication of maritime and underwater cultural heritage) – CREA-CULT-2021-COOP
- **BCThubs** (Blue Culture Technology Excellence Hubs in EU Widening Member States) - WIDERA-2022-ACCESS-04-01
- **ART4SEA** (Melting Art, Creativity and Marine Sciences to foster Ocean Literacy in the Mediterranean area) - CREA-CULT-2022-COOP

In orange: Projects coordinated by 3D Research

MOTIVATIONS: The UNESCO Ocean Decade

MOTIVATIONS : The UNESCO Ocean Decade

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

The **7 Ocean Decade Outcomes** describe the **Ocean We Want**:

- A **clean ocean** where sources of pollution are identified and reduced or removed.
- A **healthy and resilient ocean** where marine ecosystems are understood, protected, restored and managed.
- A **productive ocean** supporting sustainable food supply and a sustainable ocean economy.
- A **predicted ocean** where society understands and can respond to changing ocean conditions.
- A **safe ocean** where life and livelihoods are protected from ocean-related hazards.
- An **accessible ocean** with open and equitable access to data, information and technology and innovation.
- An **inspiring and engaging ocean** where society understands and values the ocean in relation to human wellbeing and sustainable development.

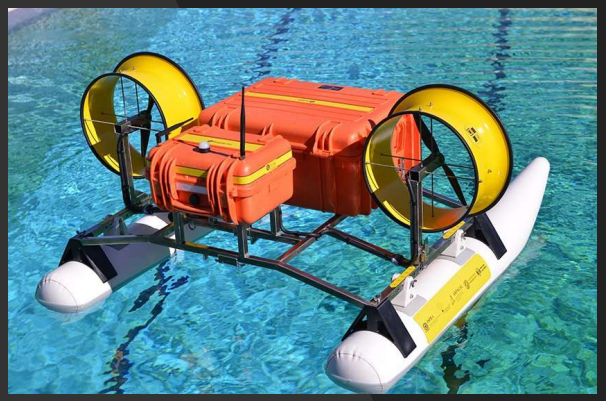
MOTIVATIONS: The 2001 UNESCO Convention

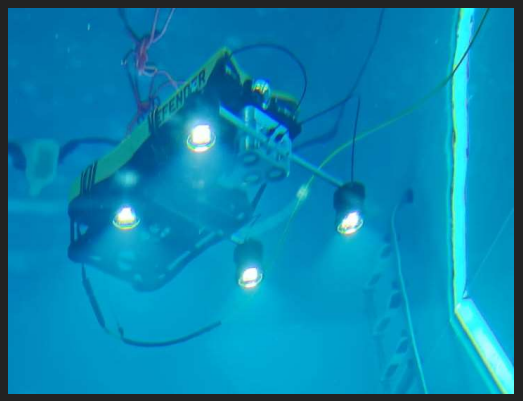
- 2001 **UNESCO** Convention on the Protection of **Underwater Cultural Heritage**:
  - "The **preservation in situ** of underwater cultural heritage shall be considered as the first option before allowing or engaging in any activities directed at this heritage."
  - **Responsible** non-intrusive **access** to observe or document in situ underwater cultural heritage shall be encouraged to create **public awareness**, **appreciation**, and protection of the heritage except where such access is incompatible with its protection and management.

AGENDA

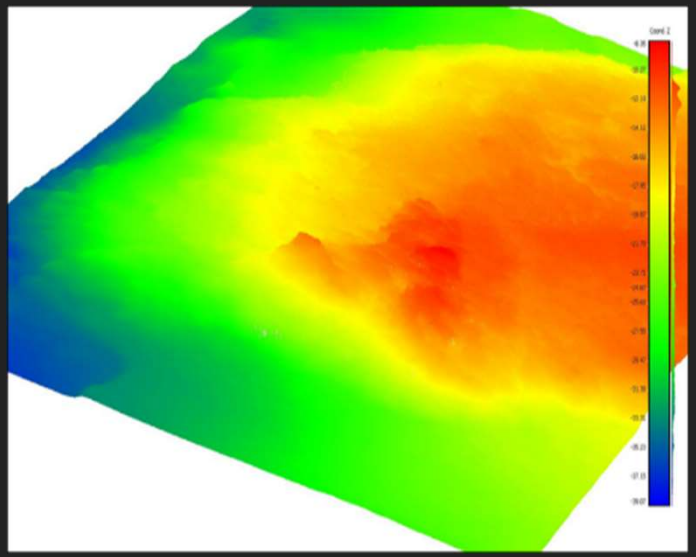
- 3D Recording of the underwater environment
- Simulating divers' experience in immersive virtual reality
- Serious Games
- Underwater Augmented Reality
- Simulating underwater robots
- Using simulation for artificial dataset creation

Underwater Remote Sensing -> Digitizing the seabed





Robotics and sensing technologies



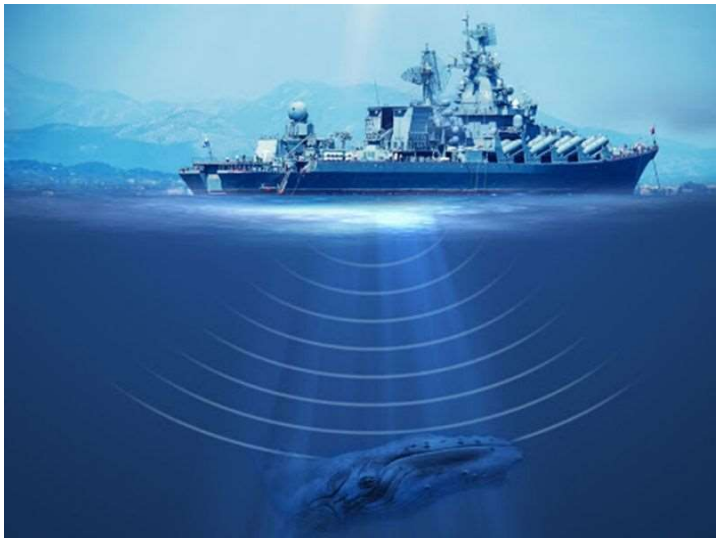
Data & Knowledge

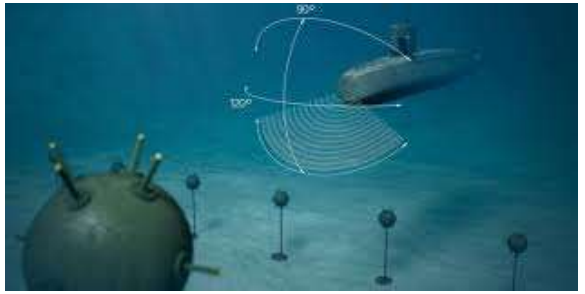
UNDERWATER REMOTE SENSING – APPLICATION FIELDS

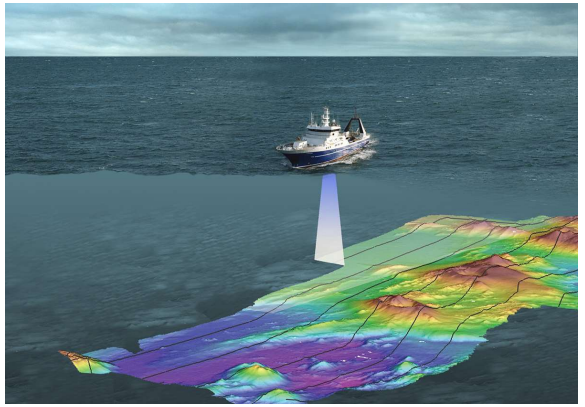
- MARINE BIOLOGY
- DEFENSE
- ENVIRONMENTAL MONITORING
- OFFSHORE INDUSTRIES
- …

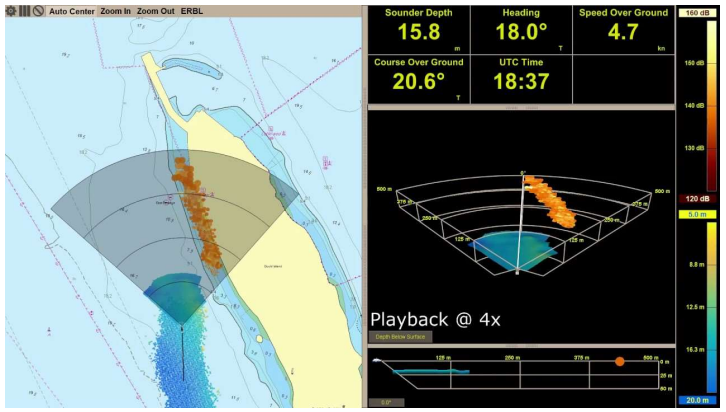
Mainly used for:

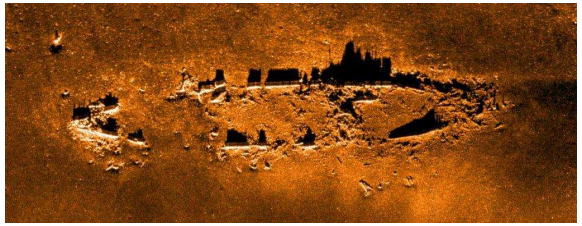
- Coastal zone management
- Search and rescue
- Climate change studies
- Data analysis
- Image interpretation
- Seafloor mapping
- Water column profiling
- Underwater exploration







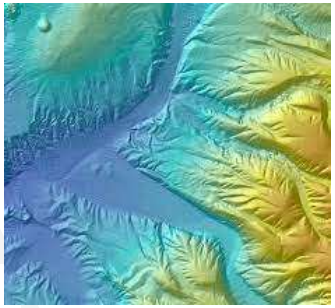


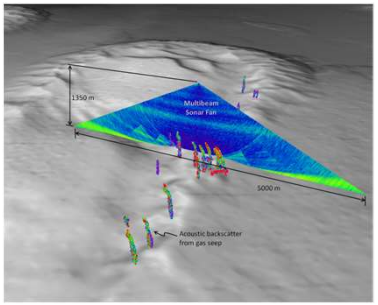


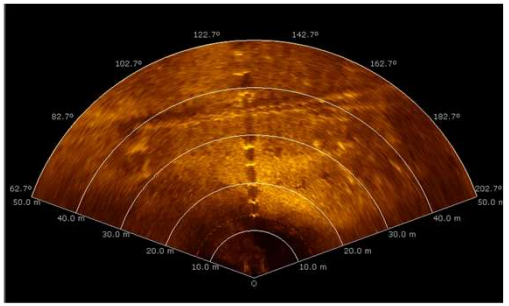
UNDERWATER REMOTE SENSING – ACOUSTIC TECHNOLOGIES

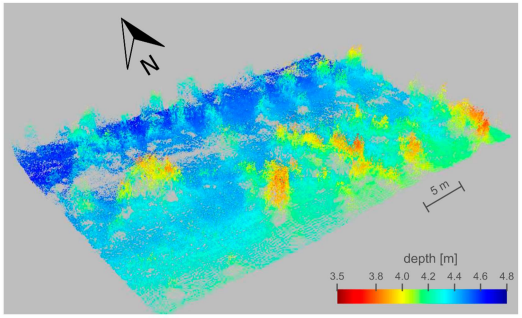
SONAR

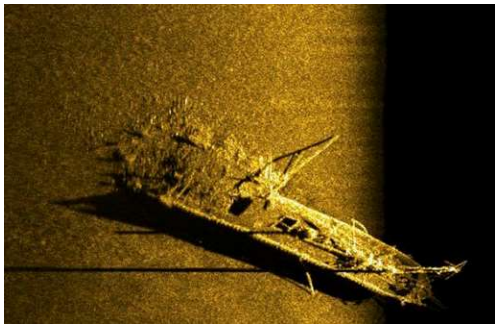
- MULTIBEAM ECHOSOUNDER (MBES)
- SIDE-SCAN (SSS)
- SUB-BOTTOM PROFILERS (SBP)
- …

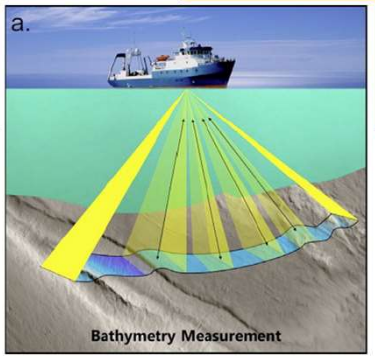


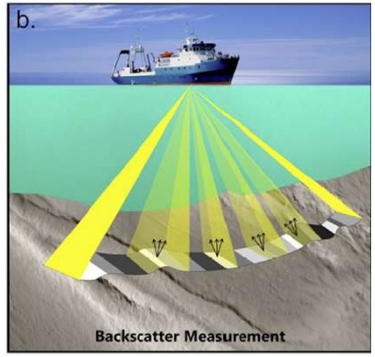


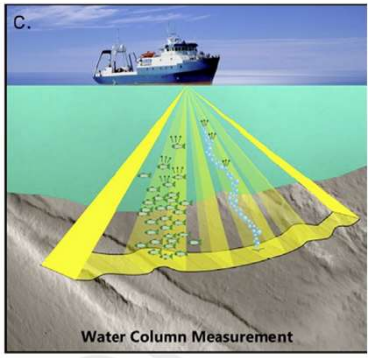








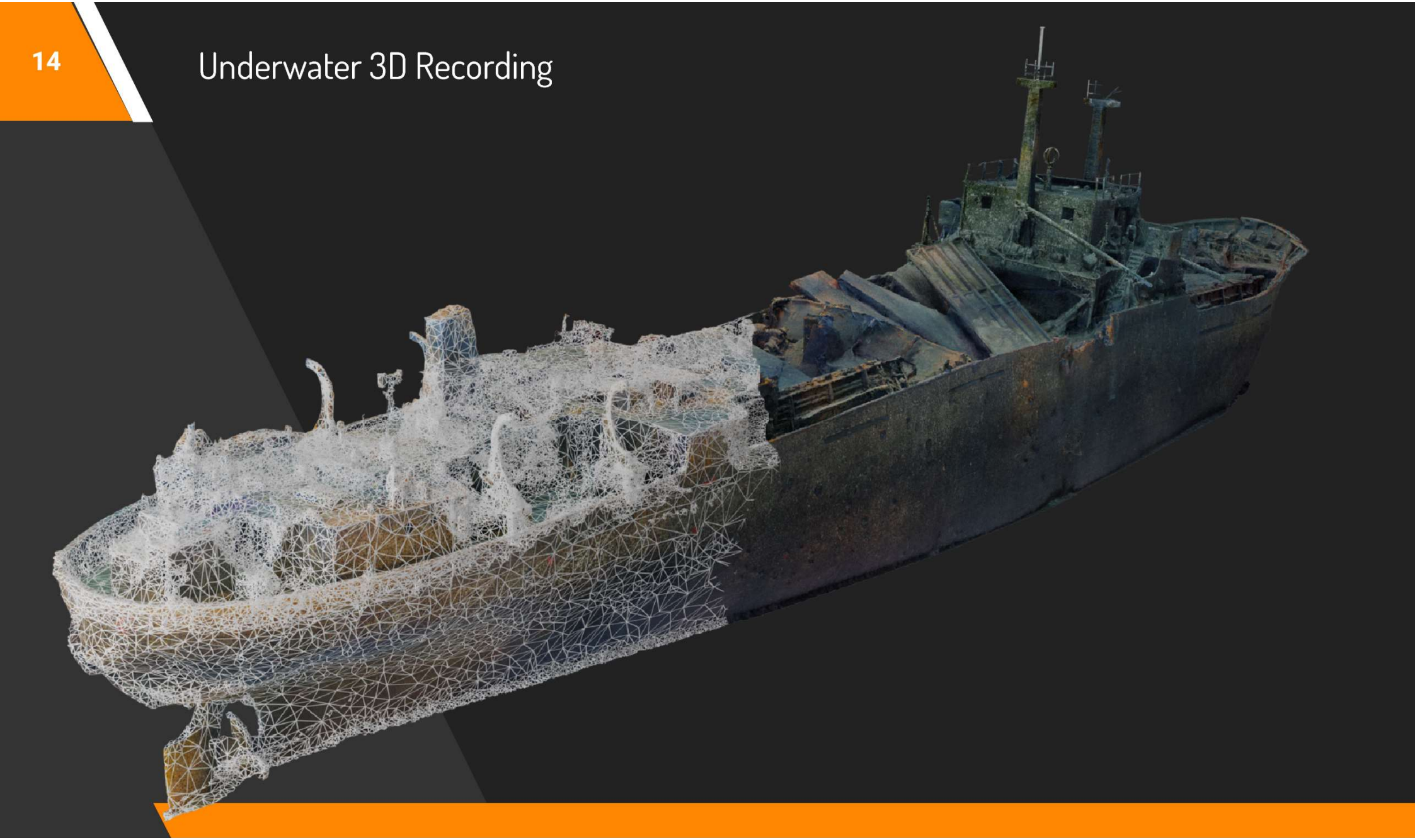




Underwater photogrammetric 3D Recording

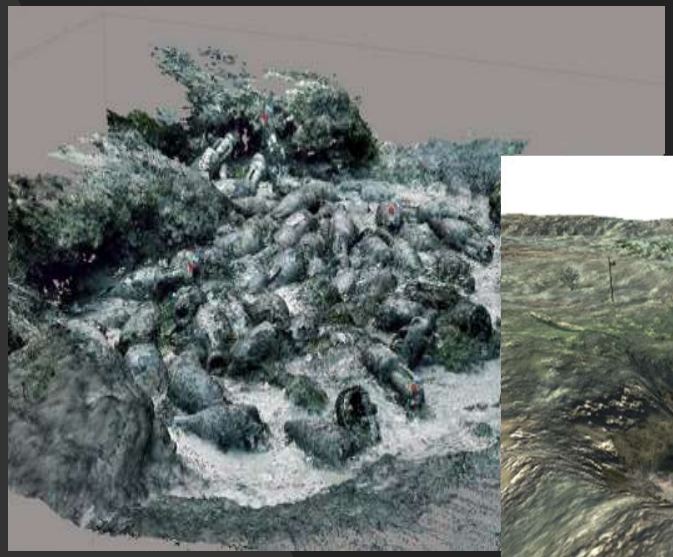
Underwater photogrammetric 3D Recording

Underwater 3D Recording

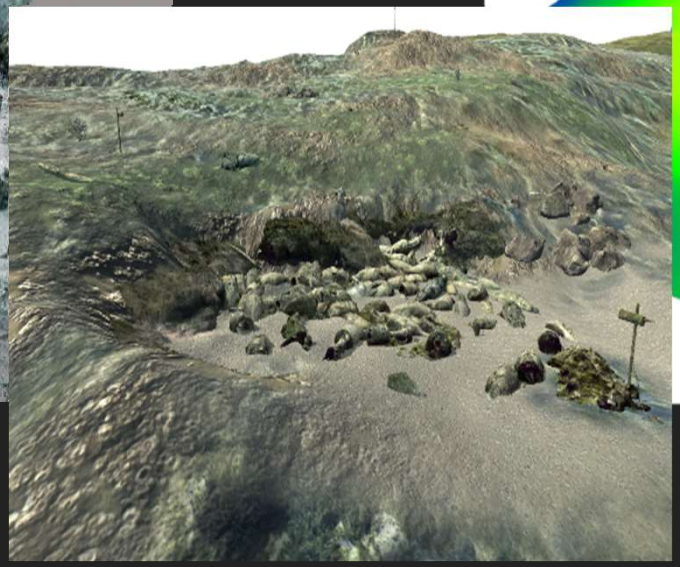


Merging optical and acoustic data

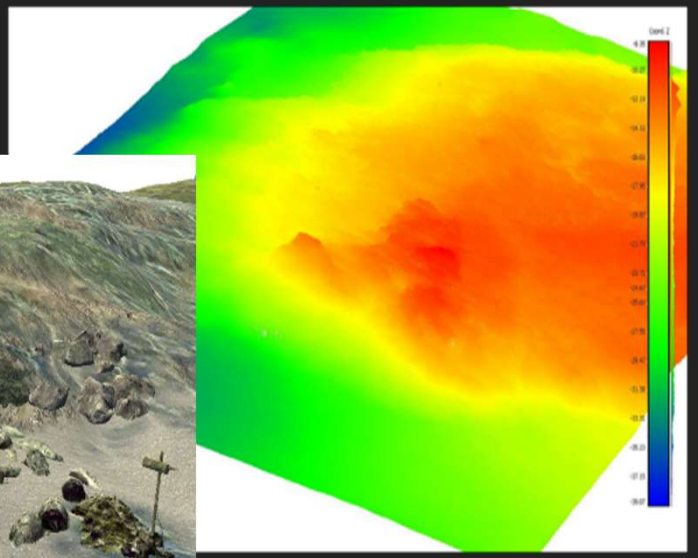
An integrated optical and acoustic survey of the underwater archaeological site allow us to obtain a multi-resolution textured 3D model of the underwater scenario.



Optical survey

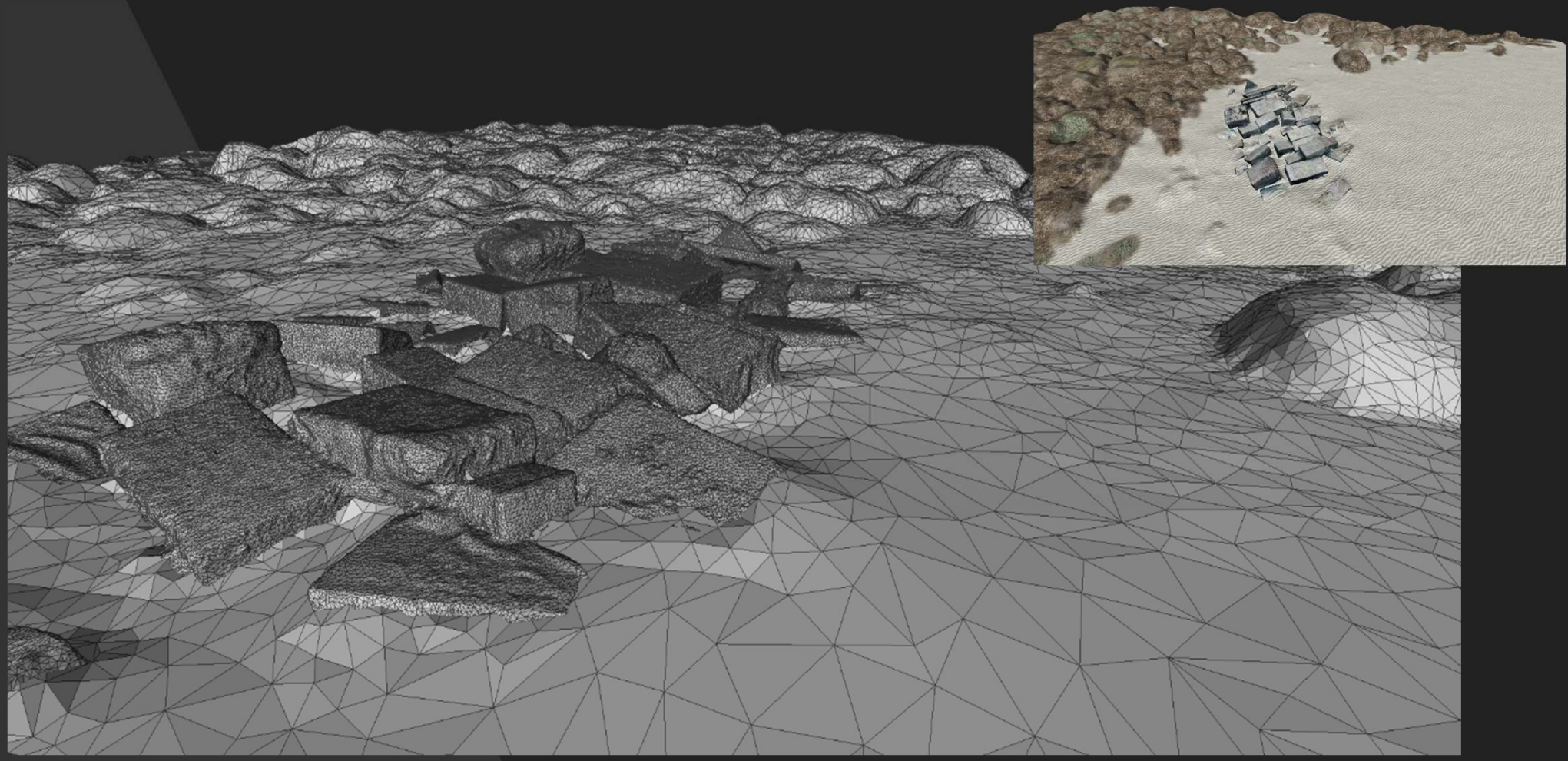


Multi-resolution textured 3D model



Acoustic survey

Merging optical and acoustic data

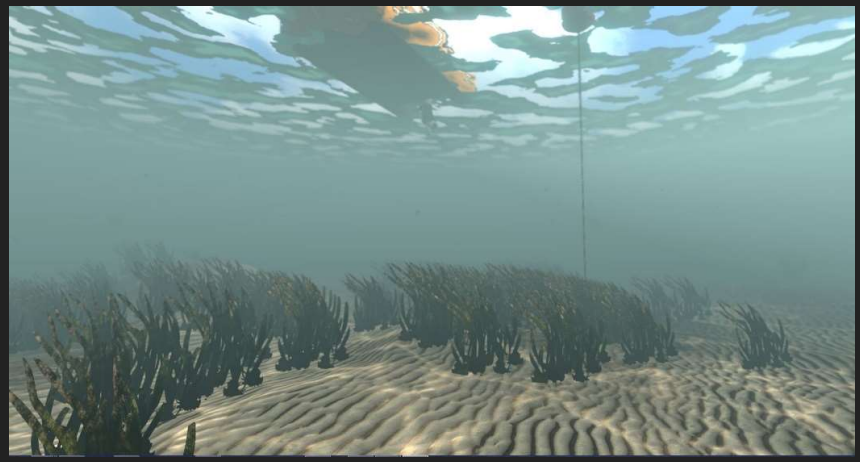


Adding terrestrial models

From 3D model to VR

Graphics effects:
Sea surface
Turbity
Reflections

Additional elements:
Flora and Fauna
Boats and buoys



Guidance:
Minimap
Indications
Diving Buddy

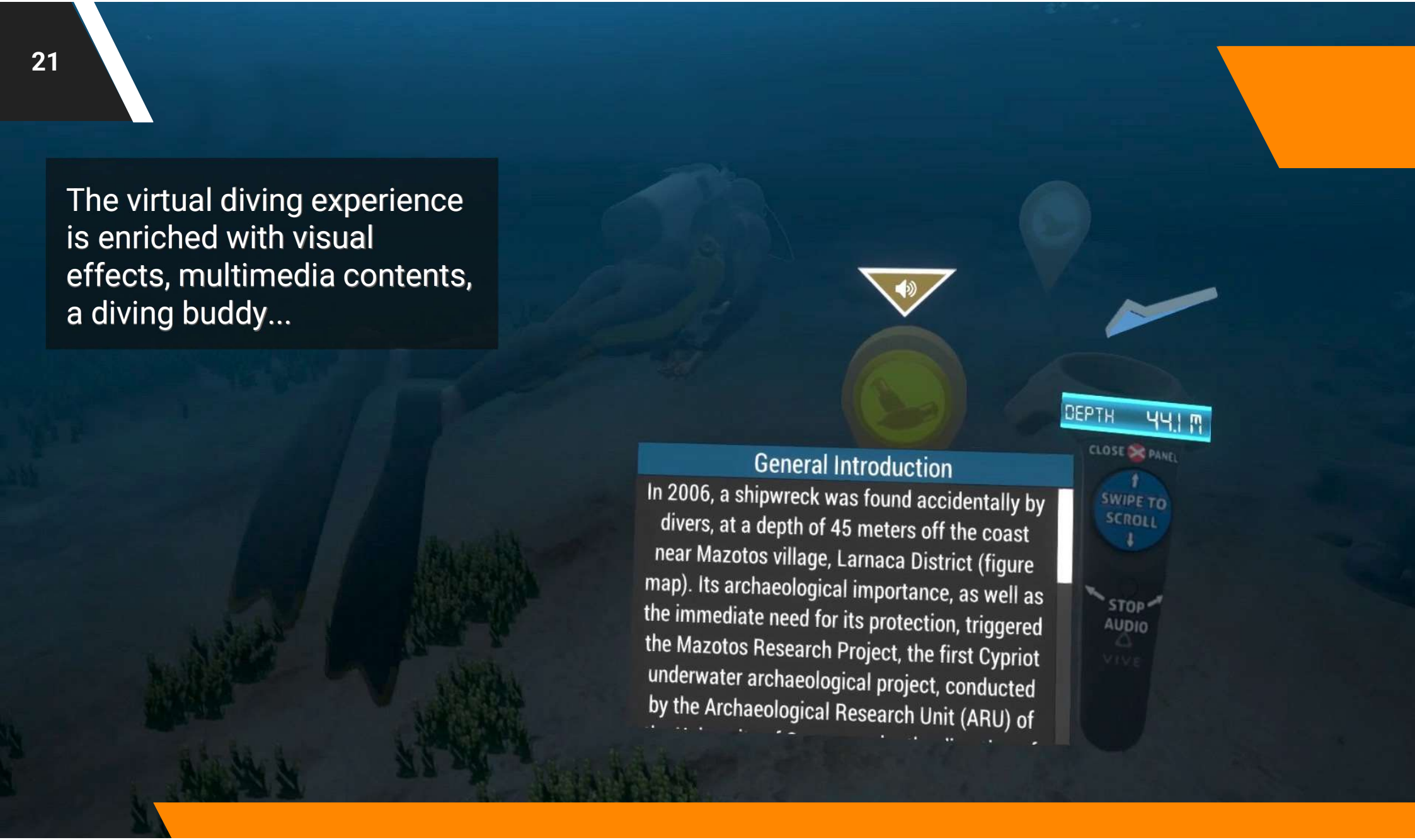
Contents:
Point of interest
Storytelling
Quests


VIVE

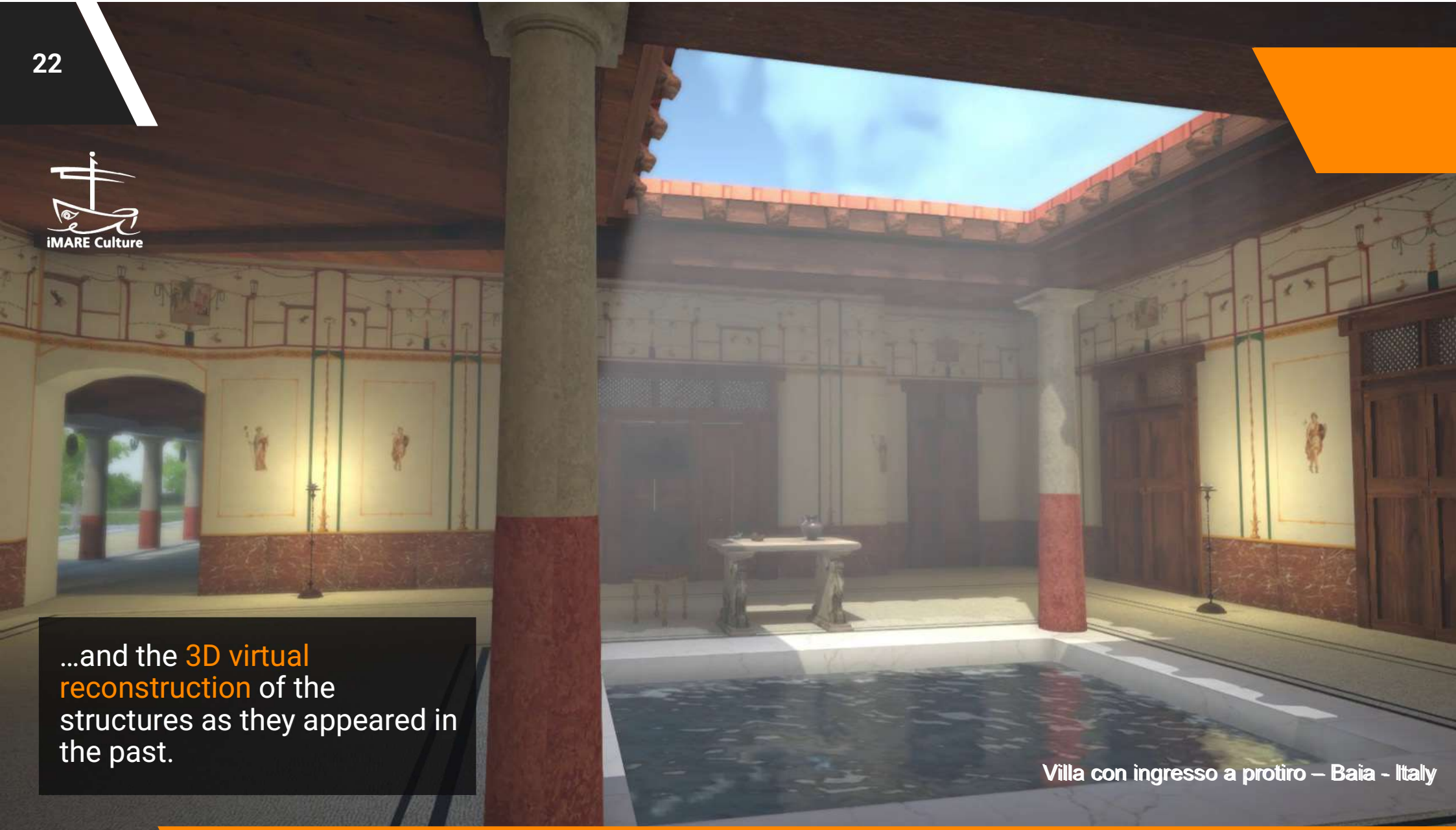
Virtual Diving is an edutainment simulation that enables users to experience a diving into the most beautiful cultural and natural underwater sites.

Christofors shipwreck – Skopelos – Greece

The virtual diving experience is enriched with visual effects, multimedia contents, a diving buddy...



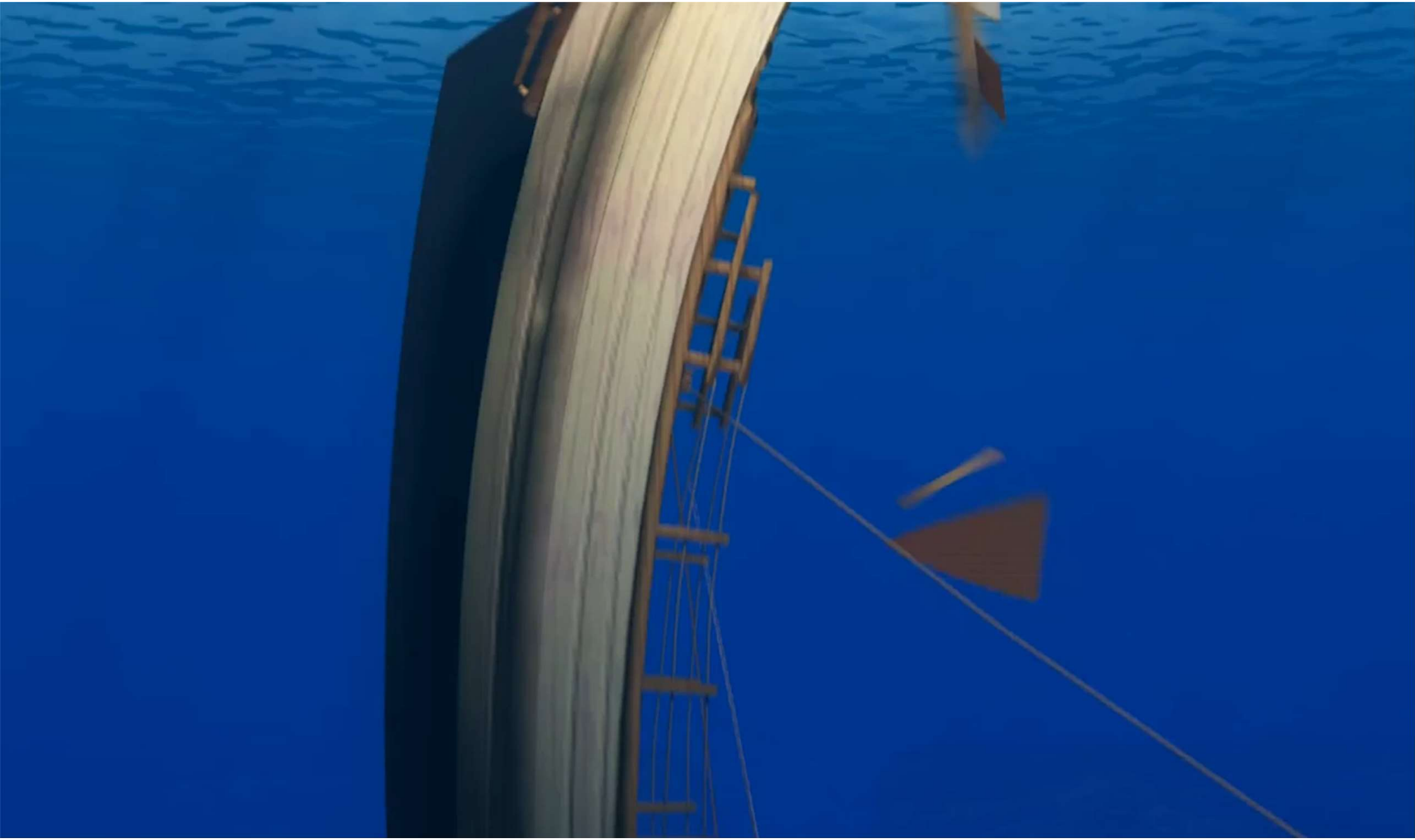
iMARE Culture



...and the 3D virtual reconstruction of the structures as they appeared in the past.

Villa con ingresso a protiro – Baia - Italy

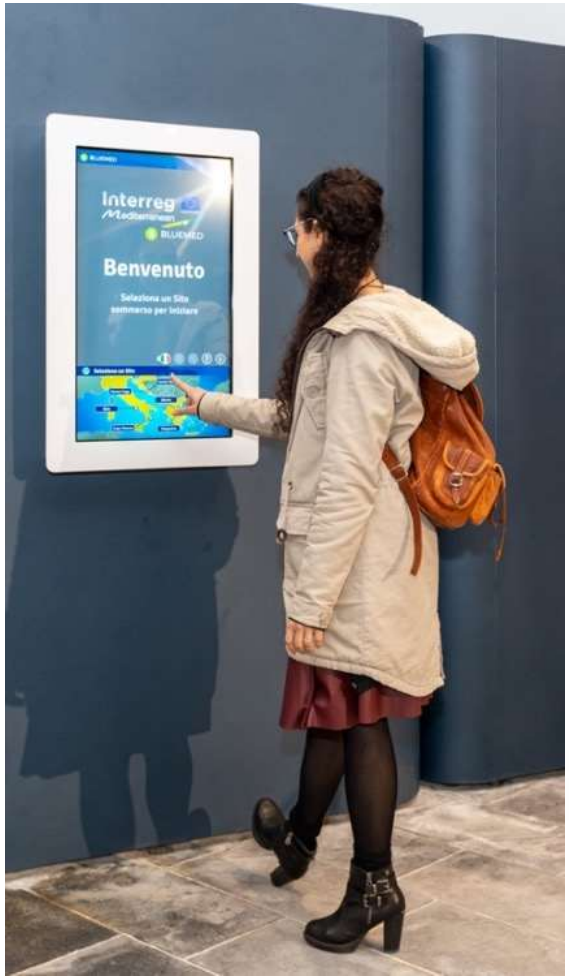
3D Modelling



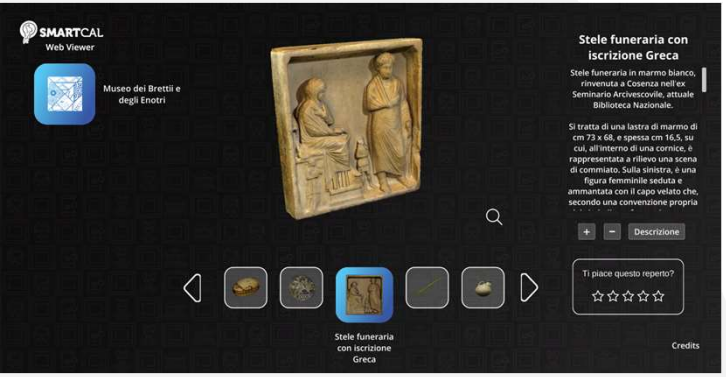
Virtual Exhibitions and Multimedia apps

Online virtual exhibitions

Mobile Apps



Serious Games



DRY VISIT – iMARECULTURE

https://bit.ly/2M3QHgP

DRY VISIT Mobile – Baiae Underwater Park

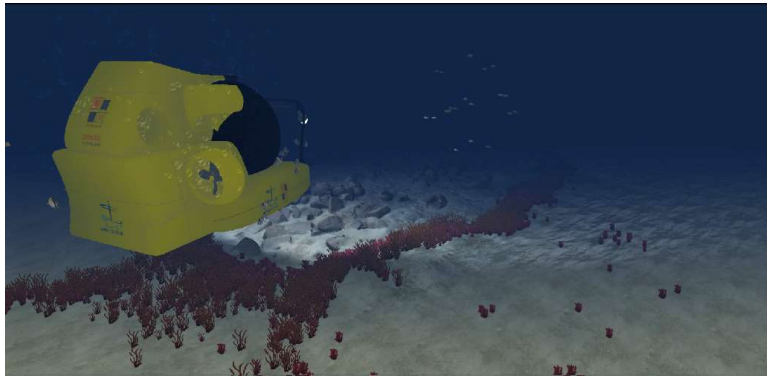
DRY VISIT
Baiae Underwater Park

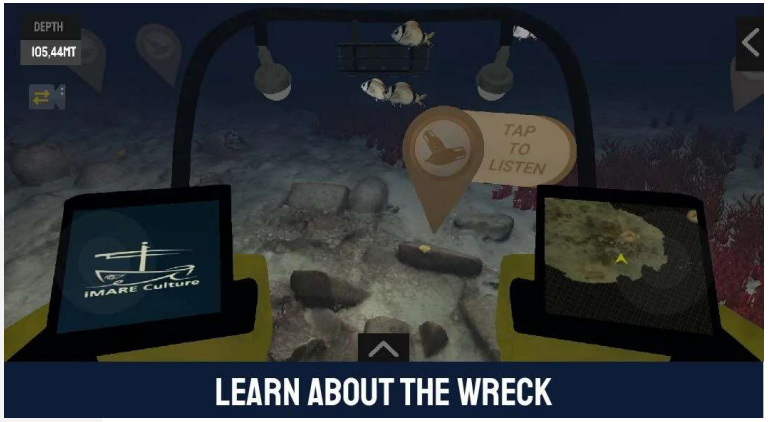
GET IT ON Google Play

Download on the App Store

DRY VISIT Mobile – Xlendi Shipwreck

DRY VISIT
Xlendi Shipwreck





GET IT ON Google Play

Download on the App Store

Virtual Diving - Christoforos

CHRISTOFOROS VIRTUAL DIVING

Meta Quest

https://bit.ly/3wQAXXm

Overall approach for Multimedia Apps and eXtended Reality

Content creators

Professionals
Digital Artists
Storytellers
Scientists

Cloud server

3D models

Video files

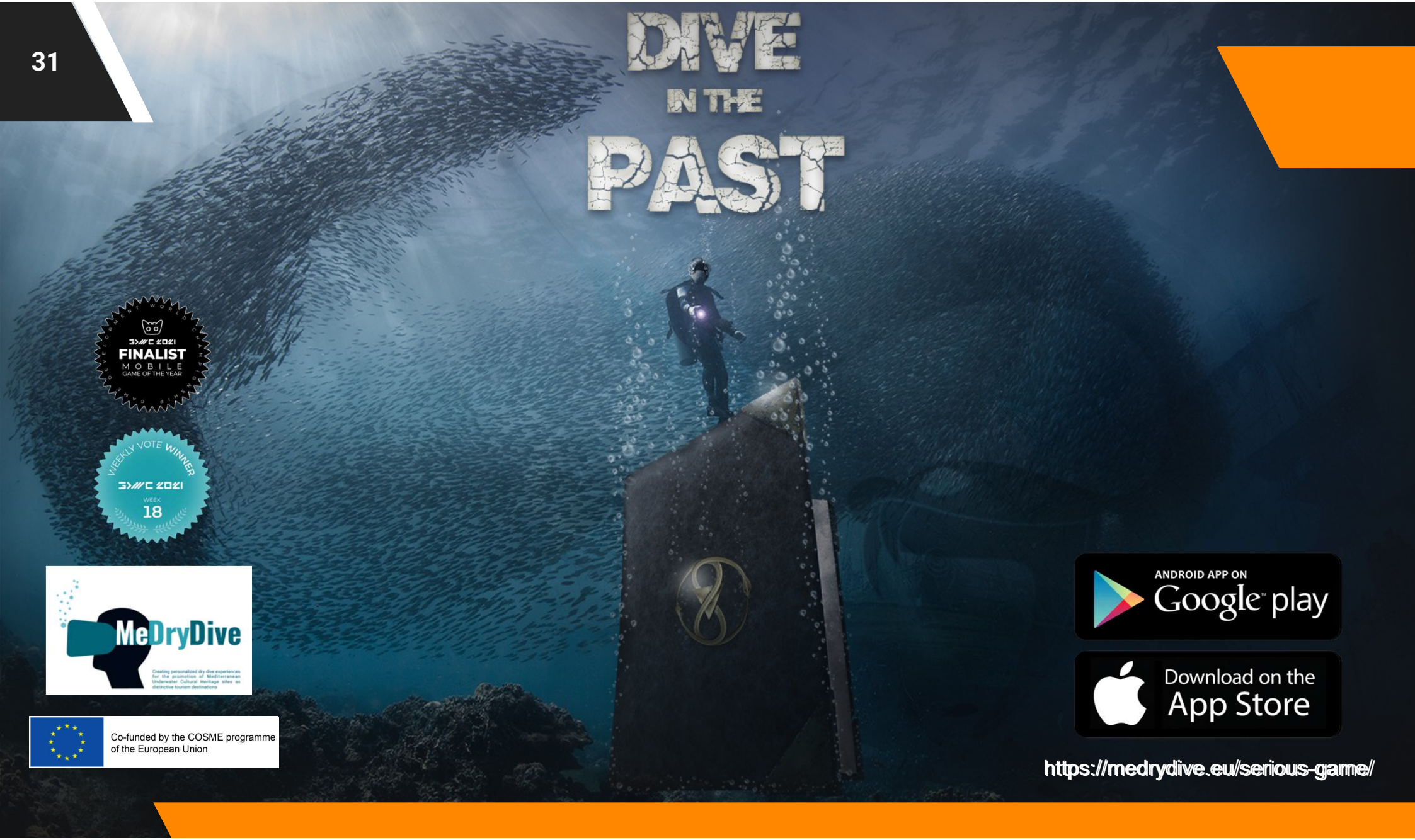
Descriptions

Audio files

Metadata

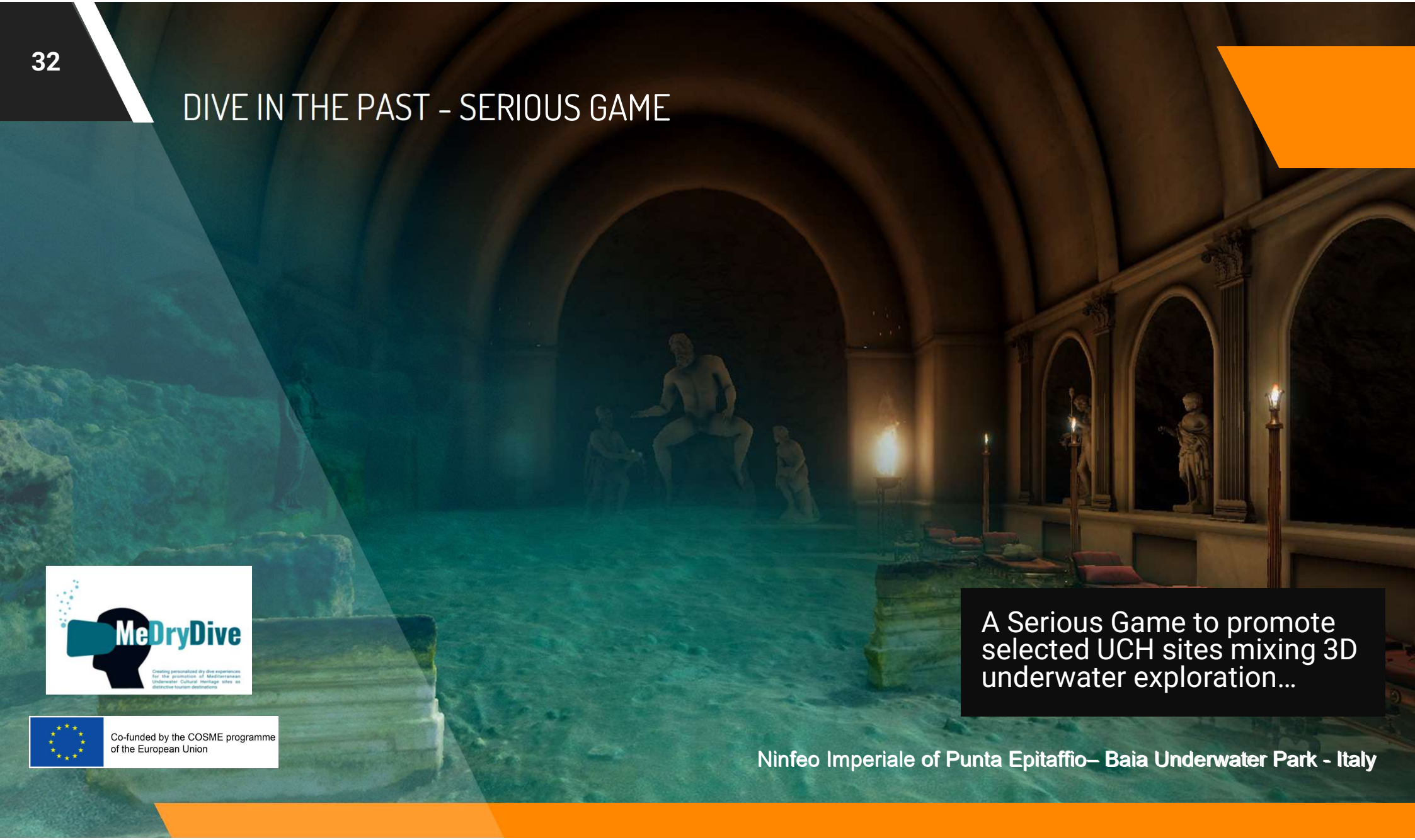
Final users

VR, AR, Museum Exhibits, multimedia apps, video-mapping installations, diving tools, serious games and video games, tools for improving work and education.



Co-funded by the COSME programme of the European Union

DIVE IN THE PAST - SERIOUS GAME



MeDryDive

Creating personalized dry dive experiences for the promotion of Mediterranean Underwater Cultural Heritage sites as distinctive tourism destinations

Co-funded by the COSME programme of the European Union

A Serious Game to promote selected UCH sites mixing 3D underwater exploration…

Ninfeo Imperiale of Punta Epitaffio– Baia Underwater Park - Italy

DIVE IN THE PAST - SERIOUS GAME

...with 2D storytelling and puzzles.

MeDryDive

Creating personalized dry dive experiences for the promotion of Mediterranean Underwater Cultural Heritage sites as distinctive tourism destinations

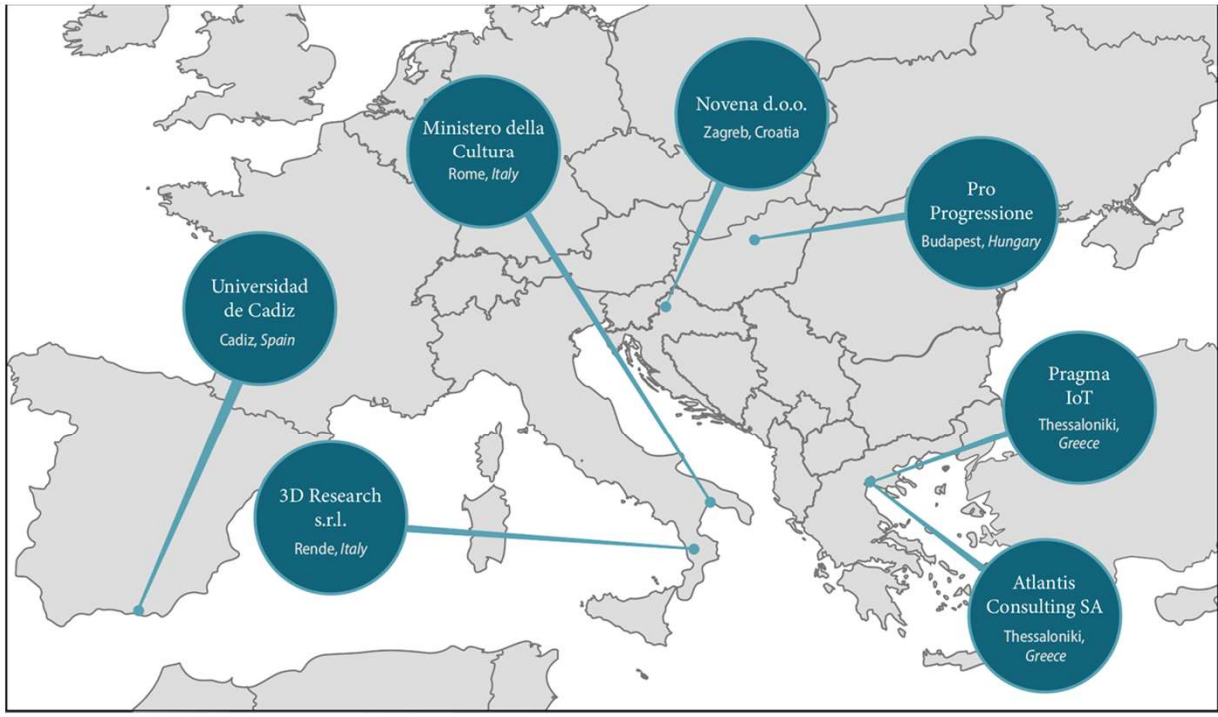
Co-funded by the COSME programme of the European Union

CREAMARE

CREAMARE

Co-funded by the European Union

- **Call:** CREA-CULT-2021-COOP managed by the European Education and Culture Executive Agency (EACEA)
- **Duration:** 01/06/22 - 30/05/25
- **Total Budget:** € 1.338.375,00



Assess communication technologies from the user perspective

UI Complexity,
Learning time

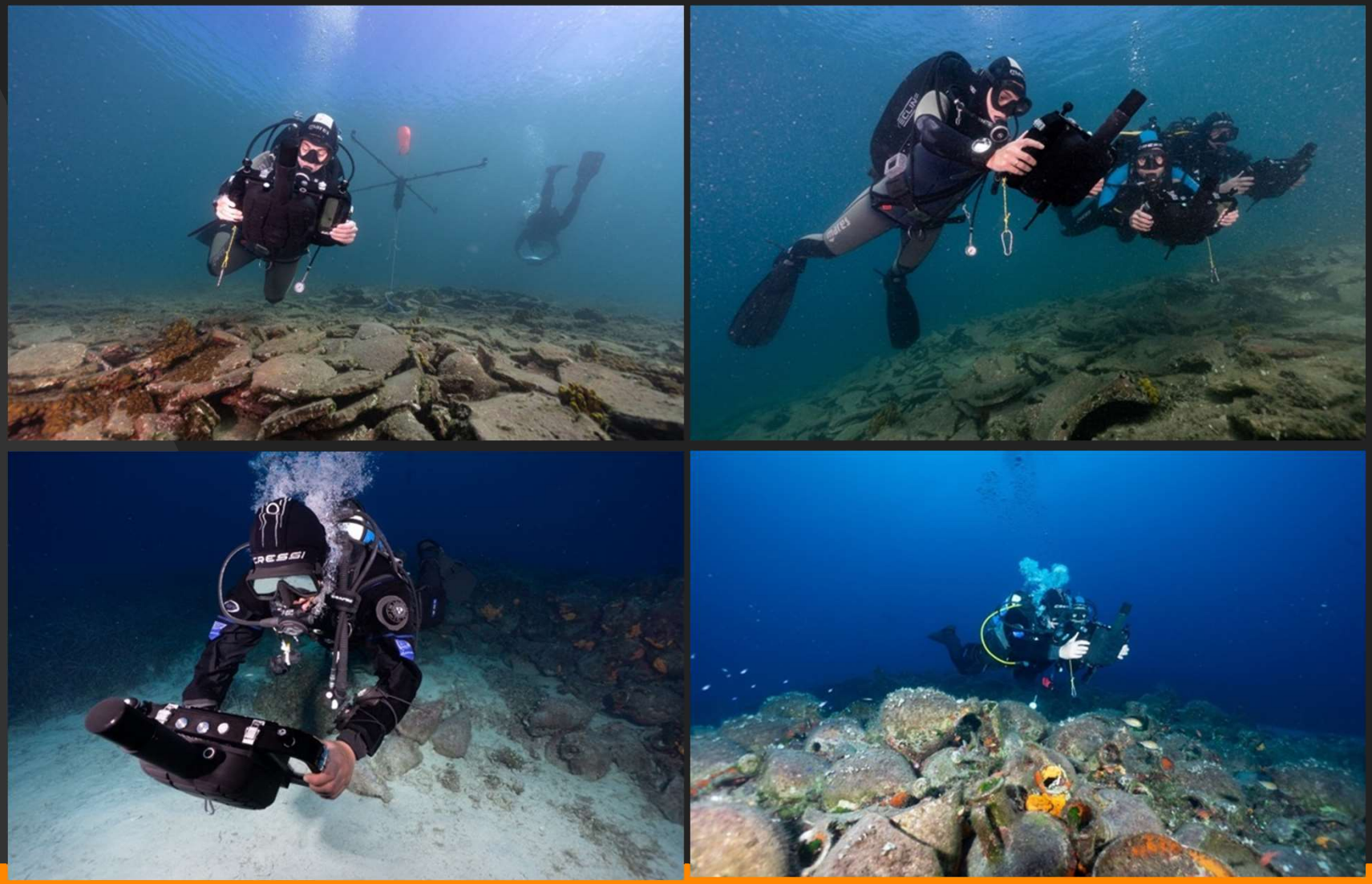
360° video

Virtual Diving

Serious Gaming

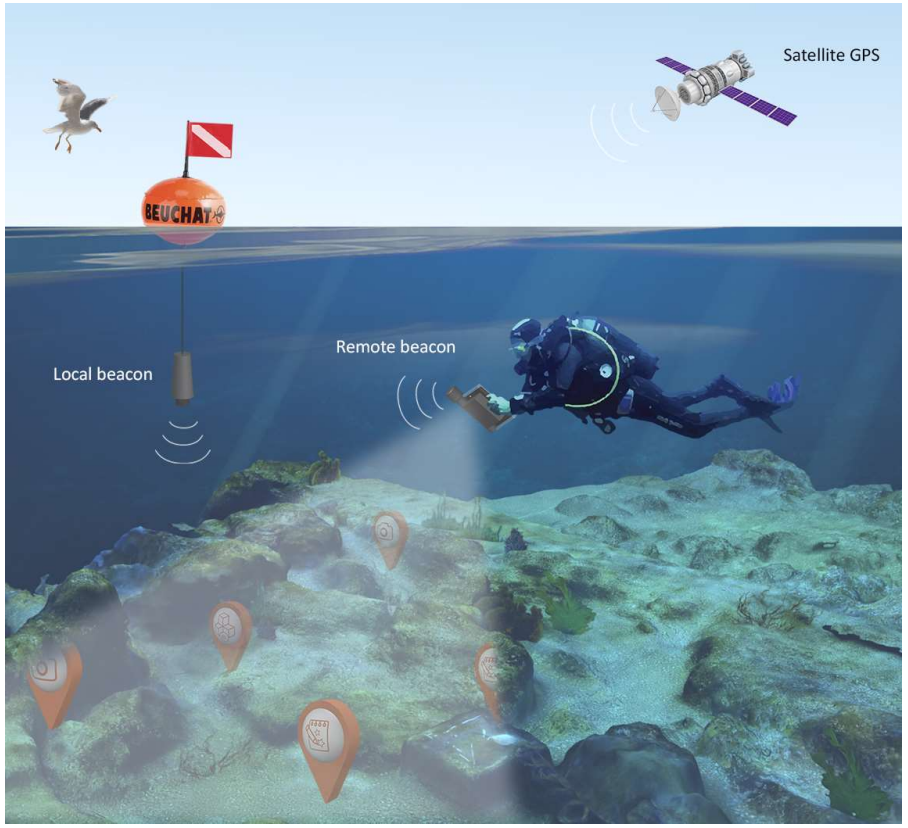
User Engagement

DIVY – Underwater Navigation and AR System



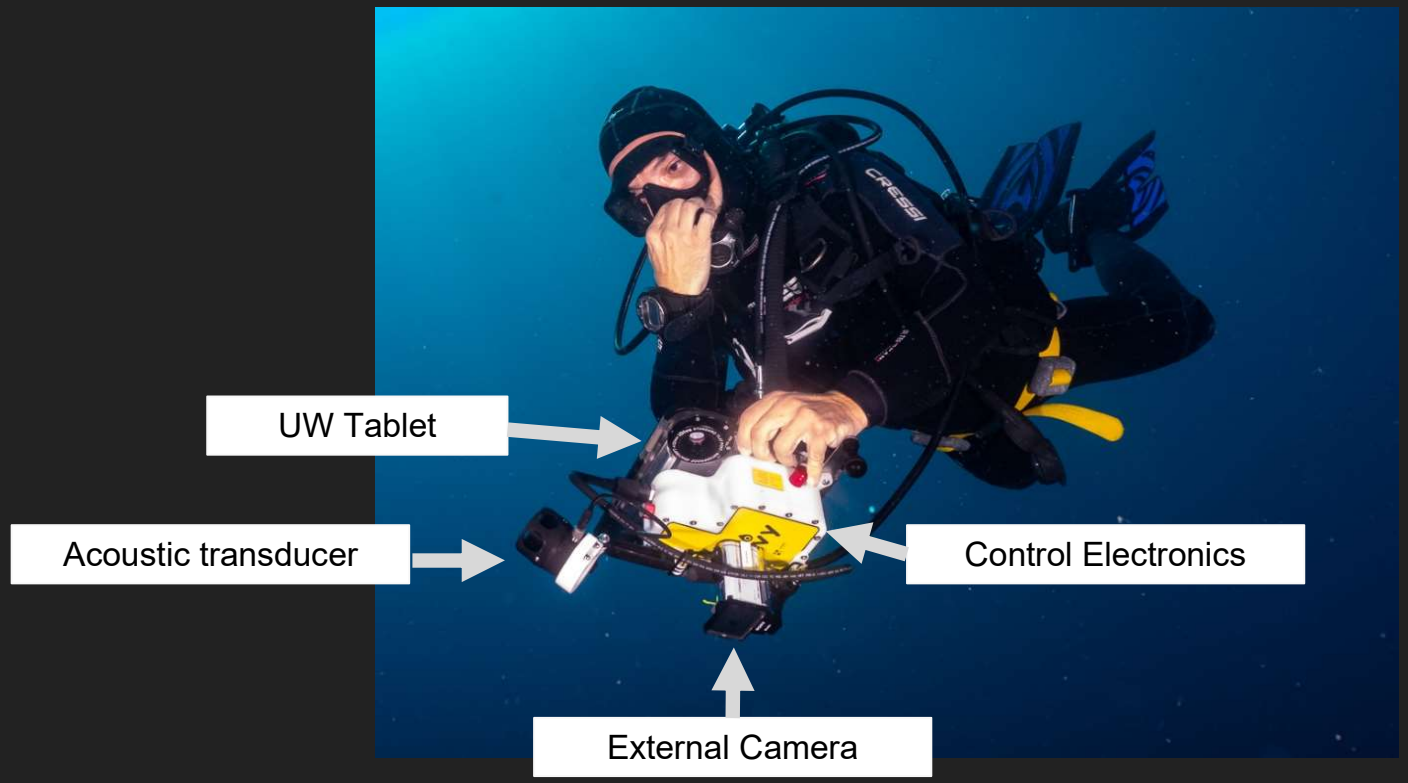
DIVY – Underwater Navigation and AR System

- Underwater Tablet
- Acoustic Positioning System
- Assisted Navigation App
- Mission Planning and Monitoring App
- Cloud platform
- DPVs and health sensors
- Autonomous Surface Vehicles



Divy supports underwater operators with:

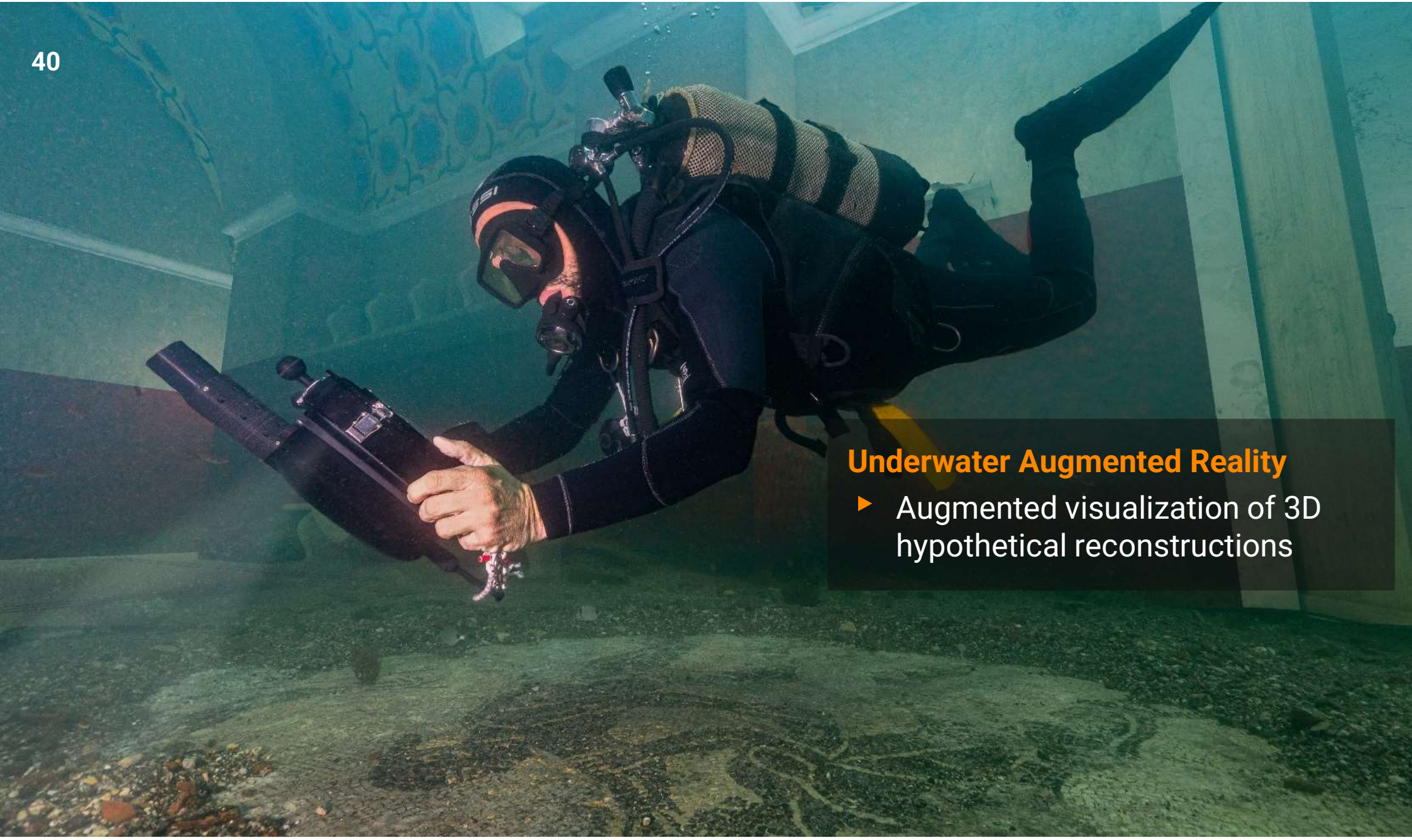
- Geolocated photos
- Mission planning and real-time monitoring from the surface
- Underwater messaging
- Target and path visualization
- Data acquisition templates
- Health Sensors and DPVs integration



Divy for recreational divers

Divy enriches the visit experience for submerged sites with:

- Assisted Navigation
- Multimedia Contents
- Underwater guided tours
- 3D virtual reconstructions
- Underwater Augmented Reality

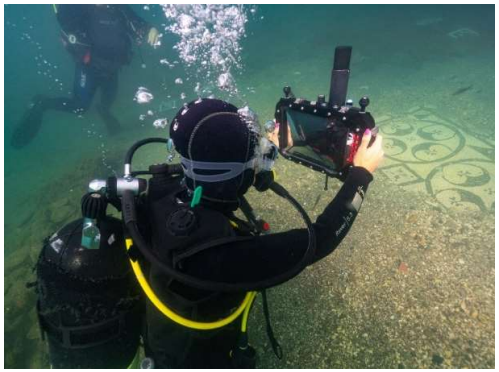


Underwater Augmented Reality

- Augmented visualization of 3D hypothetical reconstructions

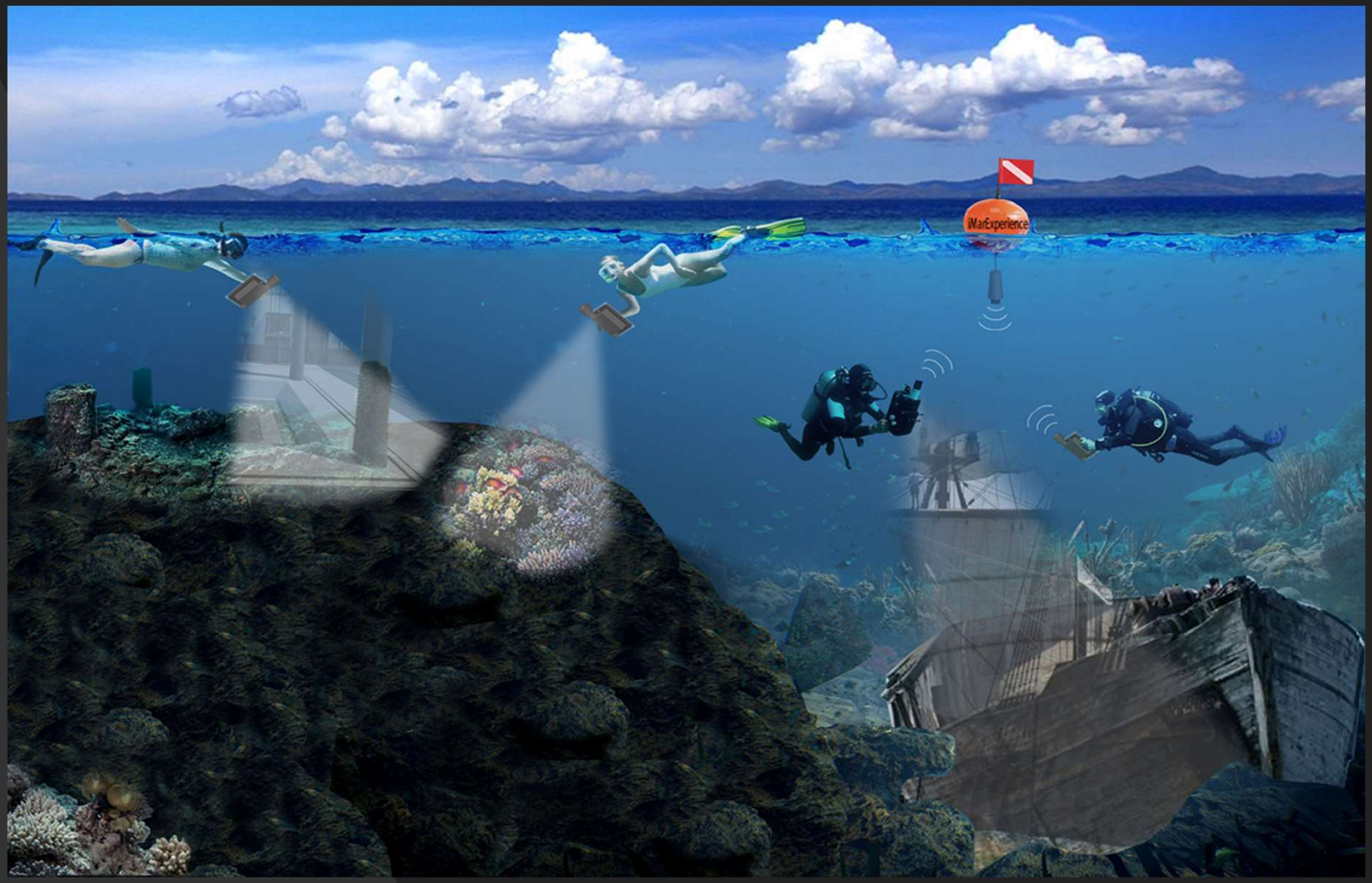
UWAR – Conclusions and open challenges

- **Conclusions**
  - On-map localization is useful in large sites or when turbidity complicates orientation and navigation
  - Tablet provides contents related to the diver position
  - AR is exciting for submerged ruins and large wrecks
  - It is a marketable touristic service



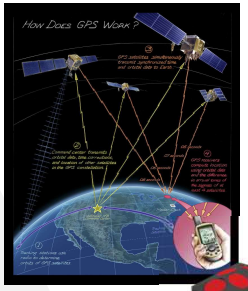
- **Open Challenges**
  - Need for faster, cheaper and more accurate acoustic localization
  - Improve ergonomics (reduce size, increase screen contrast, etc.)

UWAR - Conclusions and open challenges



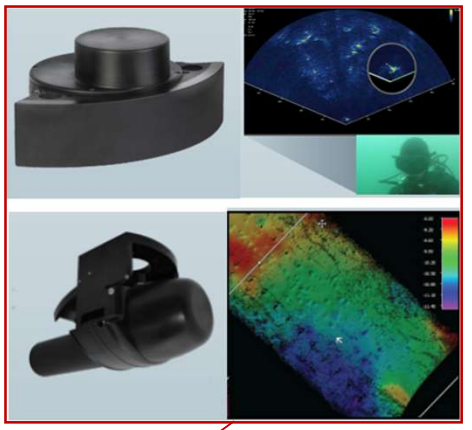
AUTONOMOUS UNDERWATER ROBOT SIMULATION

NAVIGATION SENSORS



5 THRUSTERS

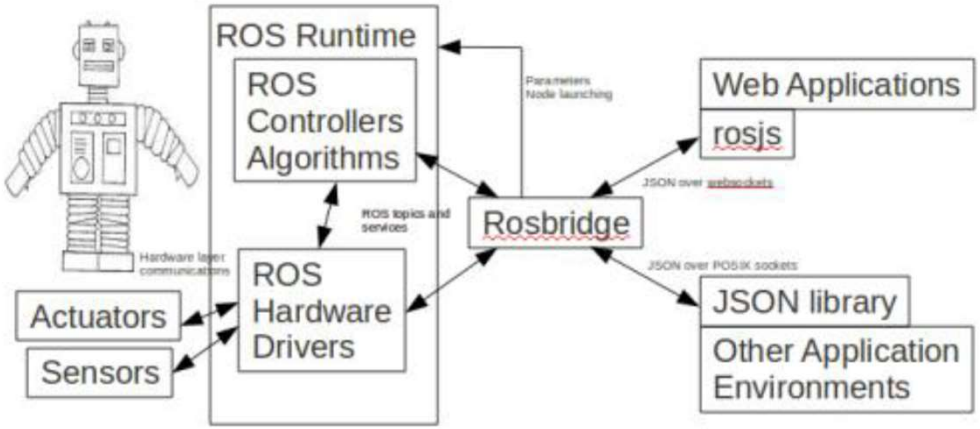
MULTIBEAM ECHOSOUNDER



VEHICLE

Architecture

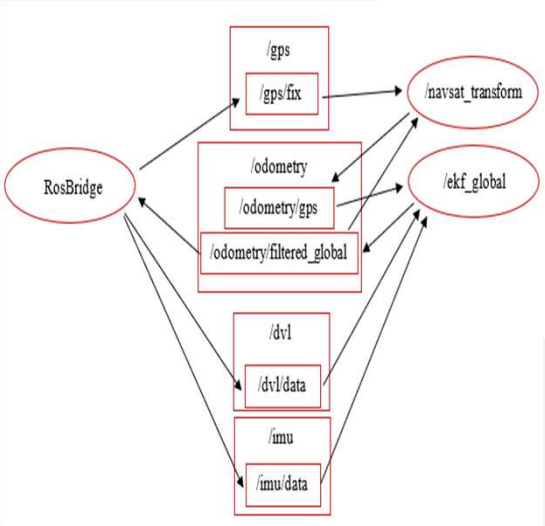
ROS ⟷ **ROSBridge** ⟷ unity



ROSSharp package

- *Publisher*
- *Subscriber*
- *Action*
- *Service*
- *Urdf*
- .

AUTONOMOUS UNDERWATER ROBOT SIMULATION



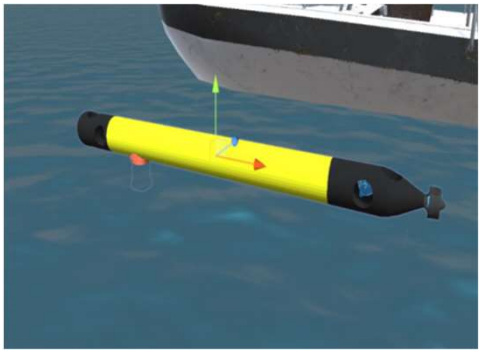
ROS

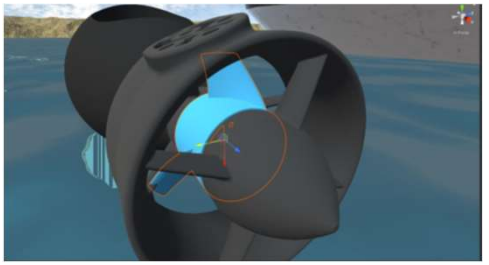
- World
  - Underwater scene
  - Robot Model
    - Sensors
    - Thrusters
    - Hydrostatic
- Vehicle Consolle
  - Commands
  - Status

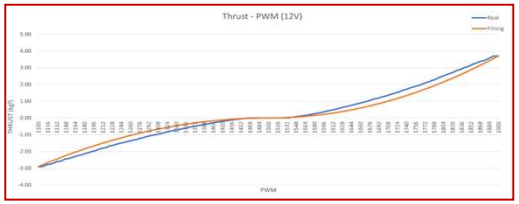
RosBridge

unity

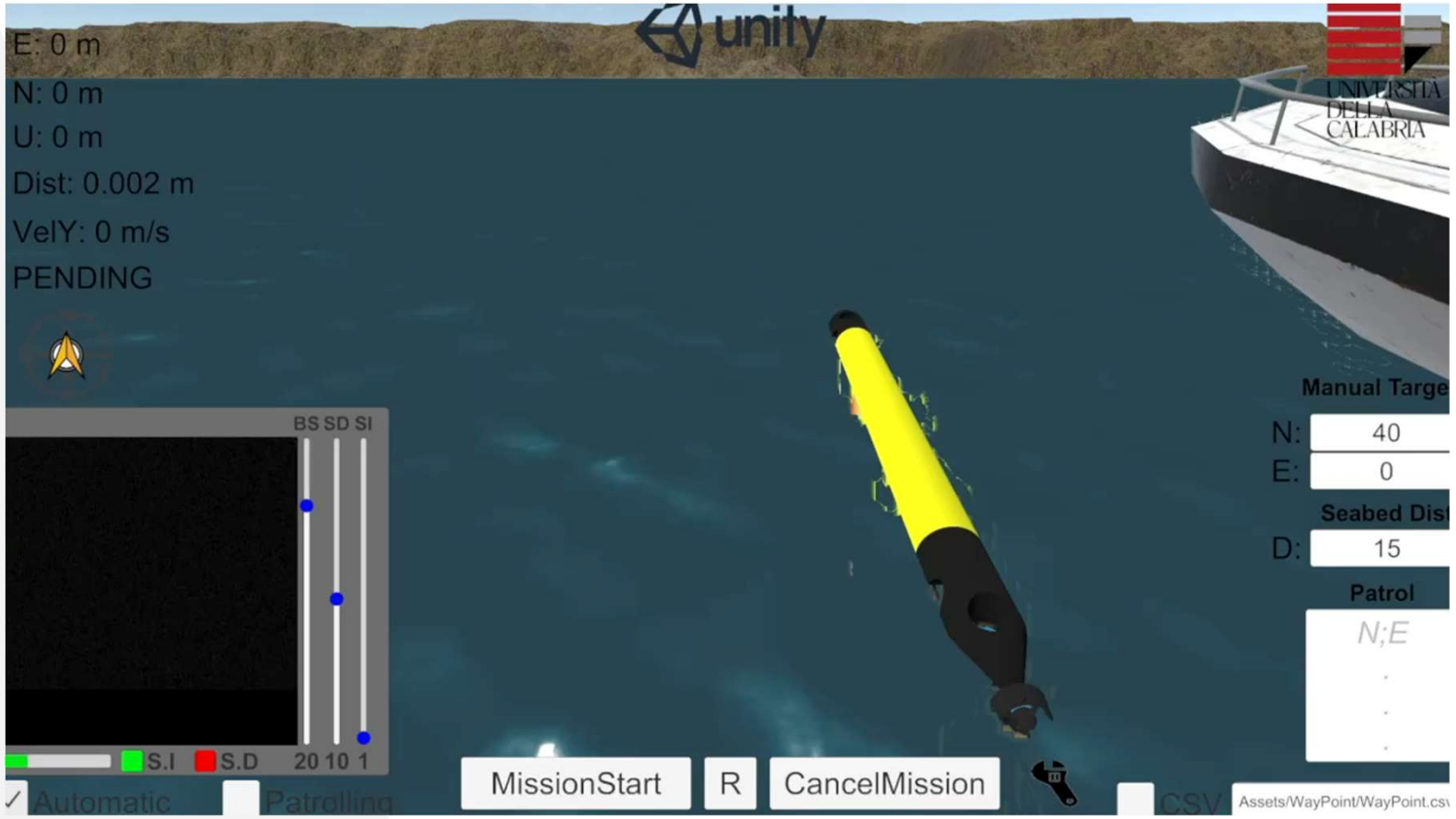
- Controll
  - Thrust
    - Allocation Matrix
    - Thrusters
    - PID
  - Navigation
    - Tf Matrix
    - Robot Localization
    - Behaviour
  - Time





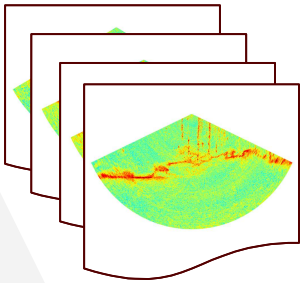


AUTONOMOUS UNDERWATER ROBOT SIMULATION



AUTOMATIC TARGET DETECTION

Manual review
- **Online**
- **Offline**



- The quantity of data is huge.
- Online detection performed by humans can introduce mismatches.
- Data have to be georeferenced.
- Time-consuming activity.

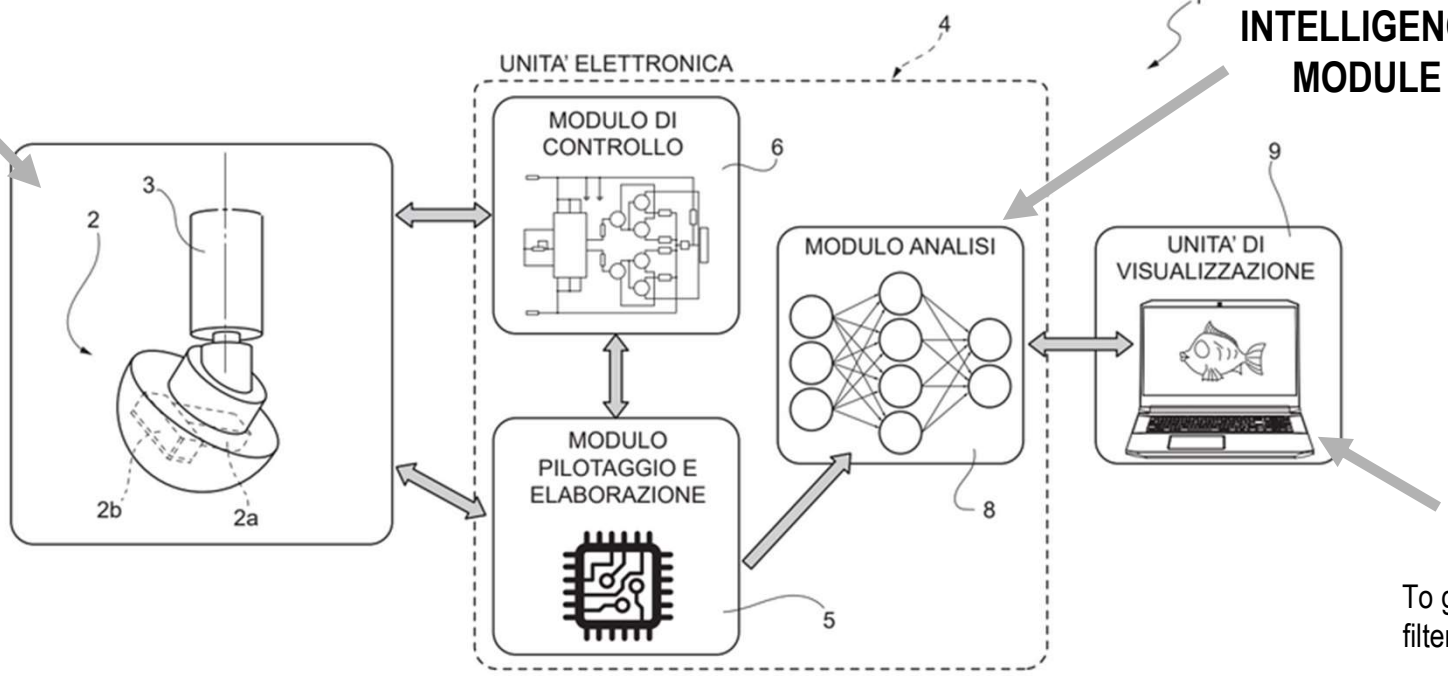
NEEDS FOR A NOVEL SOLUTION WHICH PROVIDES:

- Compatibility with the output of existing hydrography software.
- Automated target detection capabilities.
- Efficient visualization and processing of collected data.
- Georeferencing functionality for accurate spatial referencing of data.

AUTOMATIC TARGET DETECTION – GENERAL SYSTEM ARCHITECTURE

REMOTE SENSING TOOL (MBES)

Capable of acquiring a specific sector of the seafloor to facilitate the generation of a comprehensive 3D reconstruction.



ARTIFICIAL INTELLIGENCE MODULE

In order to detect hydrothermal seeps within the wedge view representation of the water column.

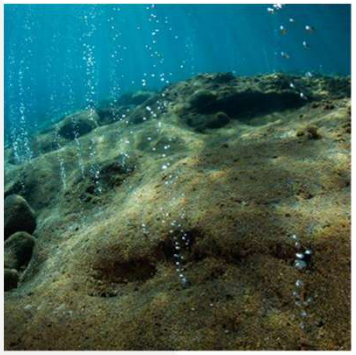
CONTROL SOFTWARE

To georeference, visualize, apply filters to, and annotate integrated data.

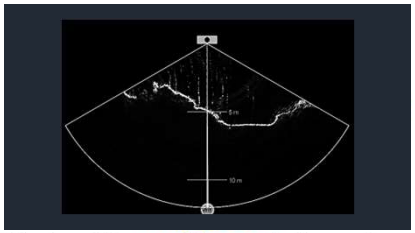
AUTOMATIC TARGET DETECTION – APPLICATION SCENARIO

TWO MAIN TASKS:

DETECTION



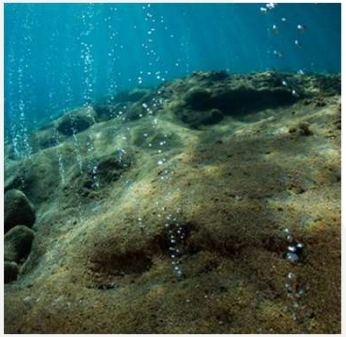
Multibeam



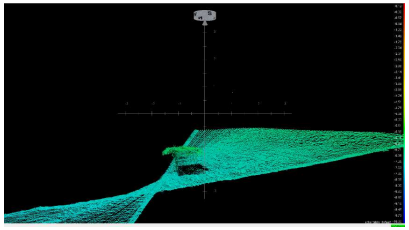
Wedge View – Water Column Data

Binary classification
1 – target in image
0 – target not in image

VISUALIZATION



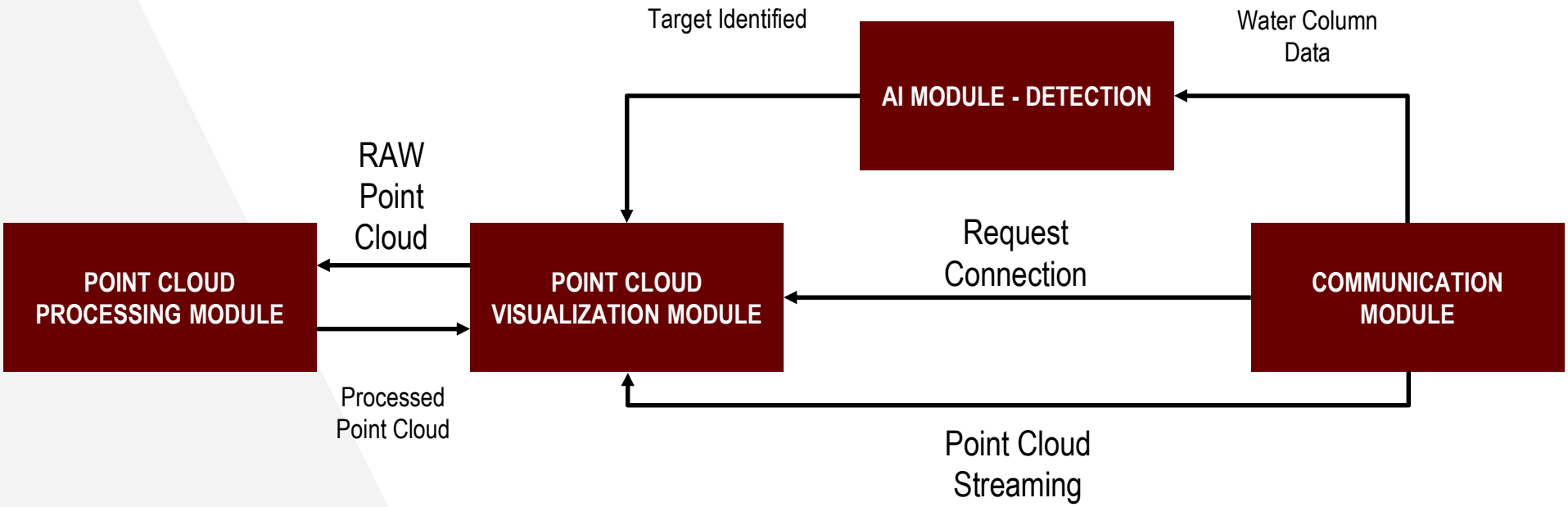
Multibeam + Pan/Tilt Mechanism



3D Point Cloud – Swath Acquisition

3D data visualization, management and storage

AUTOMATIC TARGET DETECTION – SOFTWARE ARCHITECTURE



AI MODULE FOR DETECTION – WATER COLUMN DATA PROCESSING

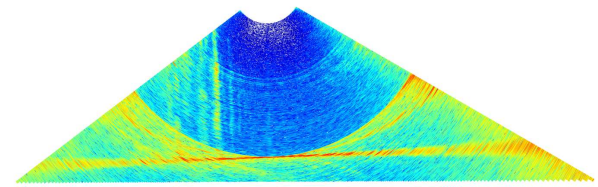
RAW DATA

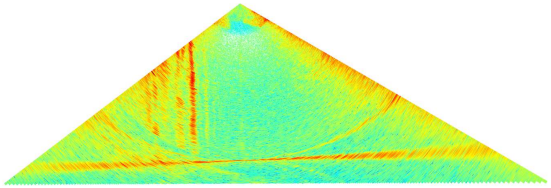
FILTERING

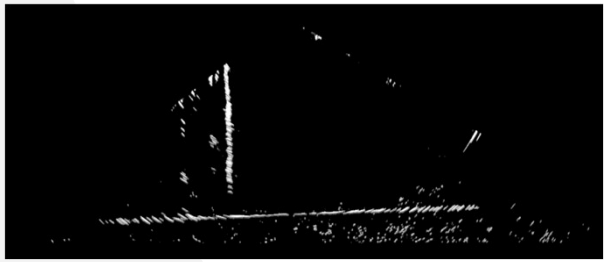
OUTPUT

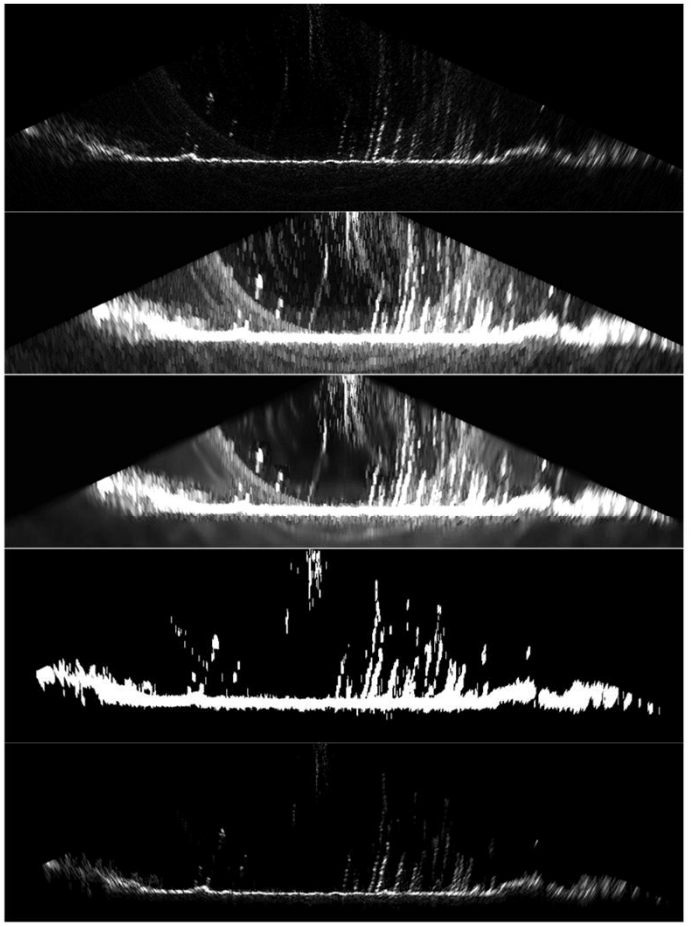
Processing time: 0.6s*

*with DELL XPS 15









Original

Dilate and Contrast

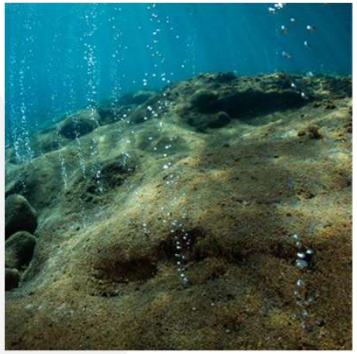
Denoise

Threshold

Final

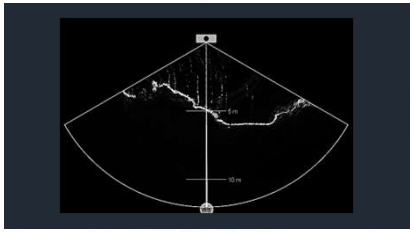
DATASET CREATION FOR CNN TRAINING

DETECTION



Multibeam

Data processing



Wedge View – Water Column Data

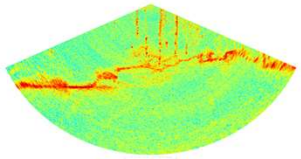
Convolutional Neural Network

Binary classification
1 – target in image
0 – target not in image

A LOT OF DATA ARE NEEDED FOR TRAINING

After-mission data

Data processing and image creation



Wedge View – Water Column Data

Bubble seeps rises **from the seafloor to the surface**. We are searching for features with this characteristic.

HOW

A. Extract water column images from .s7k ← **.s7k Viewer, Matlab, etc.**
B. Get images of the water column from MBES proprietary data format

DATASET CREATION FOR CNN TRAINING

BOTTLENECK

POOR DATASET

- Time- and cost-consuming activities to collect real-world data
- Non-representative dataset

SOLUTION

DATA AUGMENTATION

- Applied to the dataset

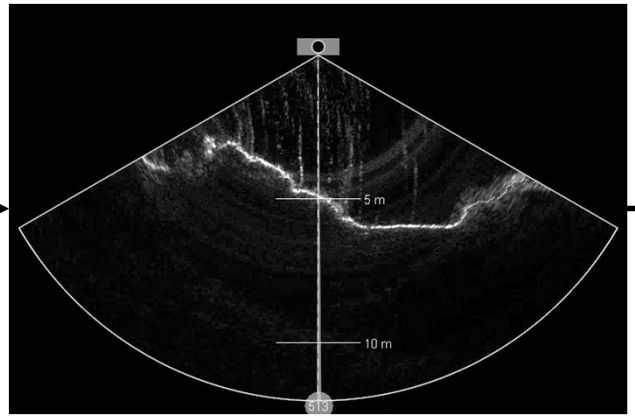
SYNTHETIC DATA

- Generated in a simulation environment

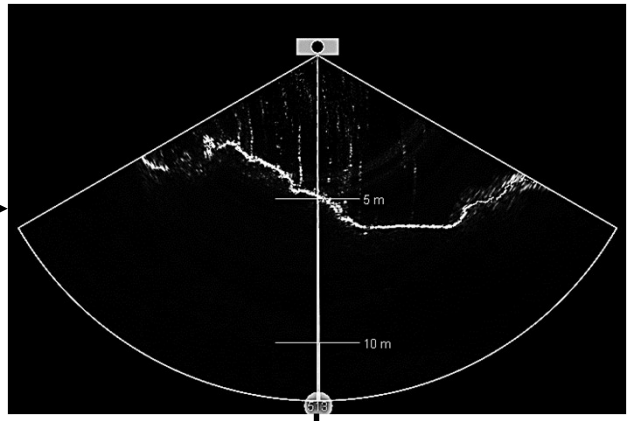
MBES MODELING APPROACH – PROBLEM FORMULATION, OBJECTIVES

ACQUISITION CAMPAIGN

PROS: PHYSICALLY EXACT SOLUTION
CONS: DIFFICULT TO MODEL/SIMULATE
NOTE: NOT THE FINAL OUTPUT



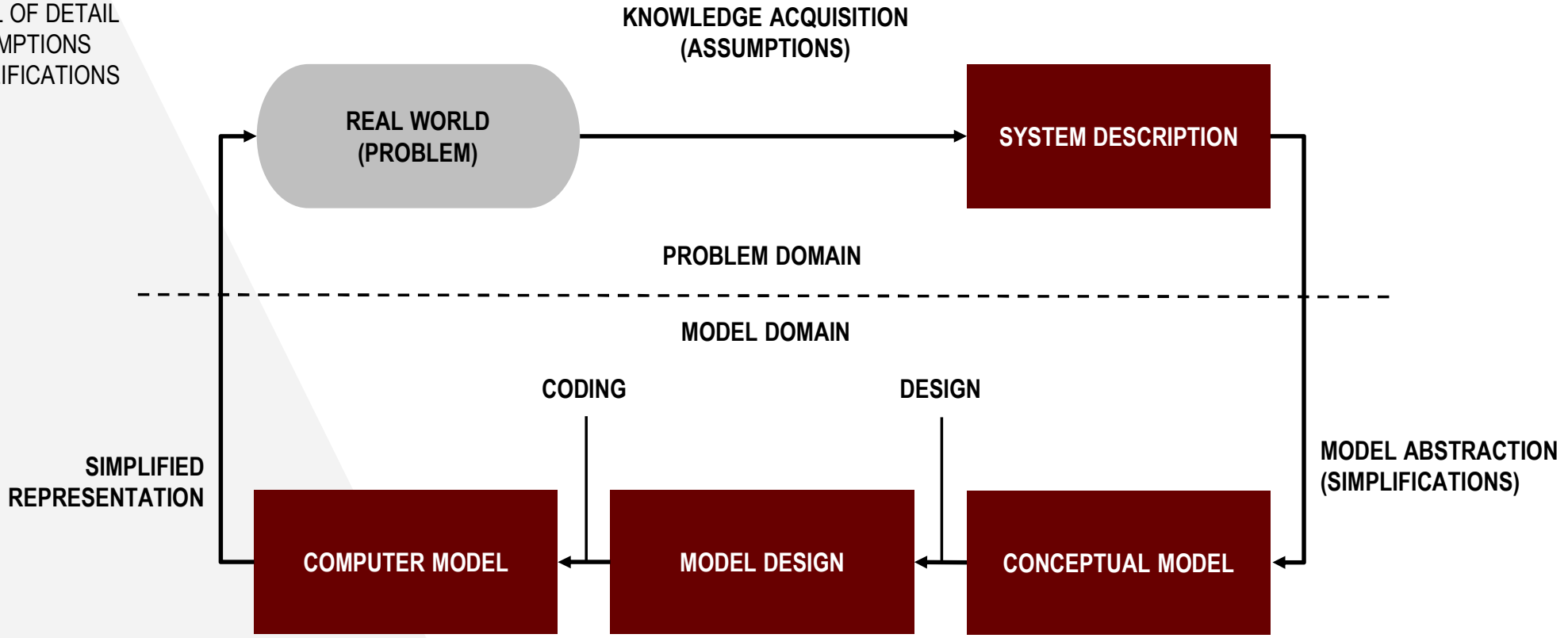
PROS: EASY TO SIMULATE
CONS: LESS INFORMATION
NOTE: INPUT TO AI MODEL



AI MODEL

MBES MODELING APPROACH - METHODOLOGY

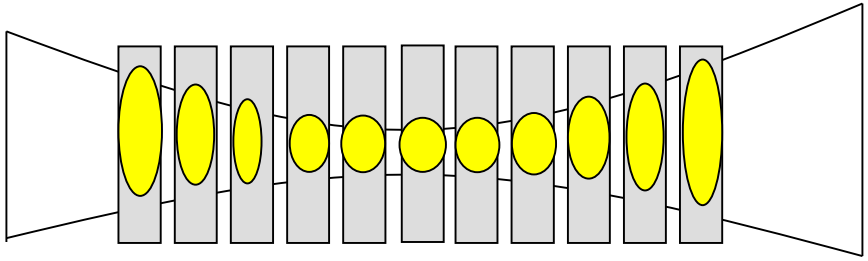
- SCOPE OF THE MODEL
- LEVEL OF DETAIL
- ASSUMPTIONS
- SIMPLIFICATIONS



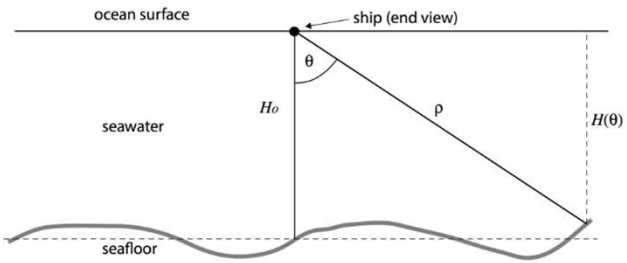
MBES MODELING APPROACH – CONCEPTUALIZATION

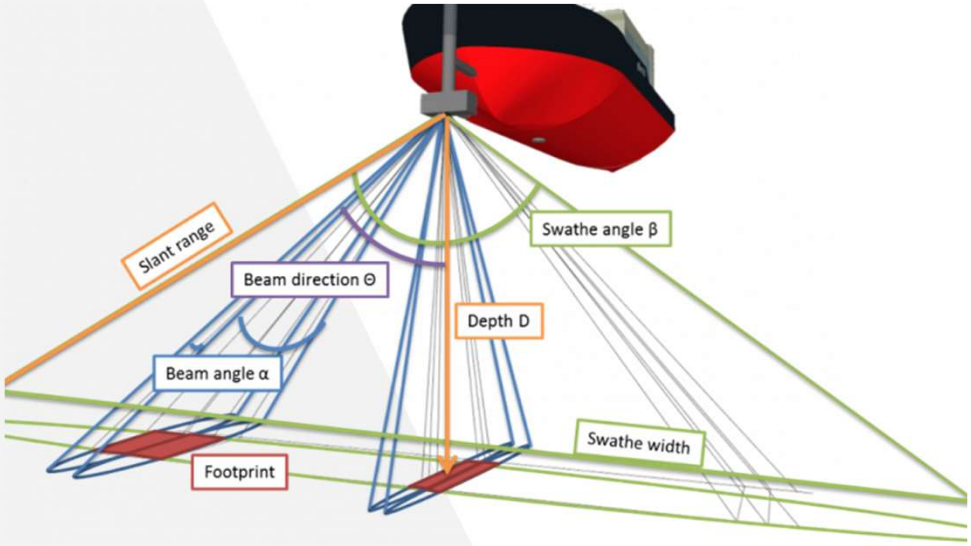
Transmit beam:

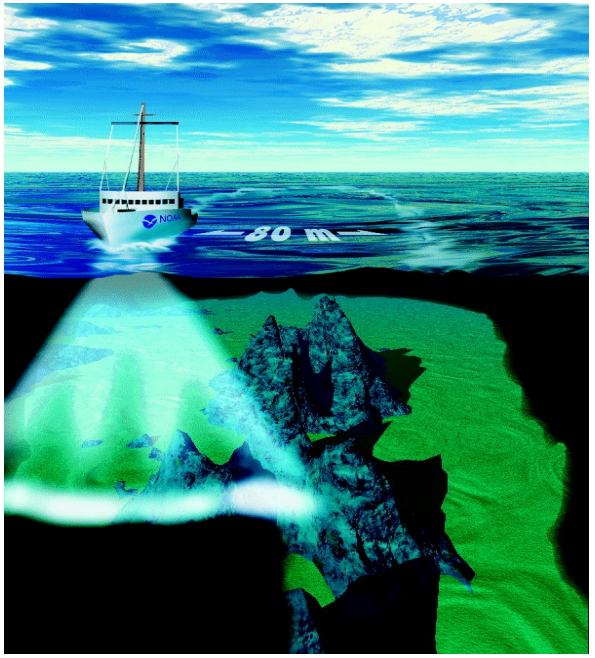
Receive beams:



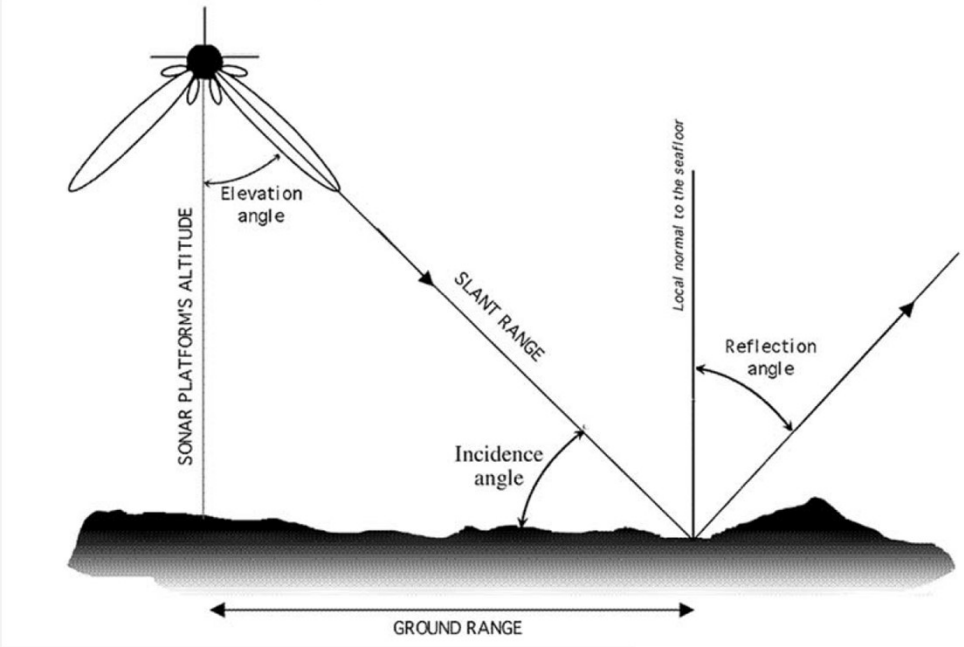
Resulting Multibeam Footprints

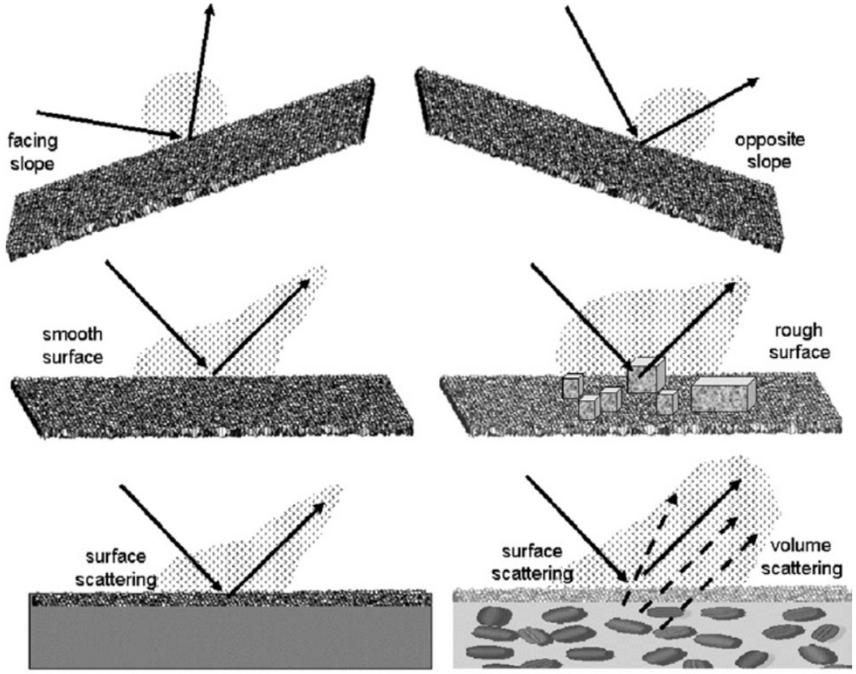






MBES MODELING APPROACH – CONCEPTUALIZATION

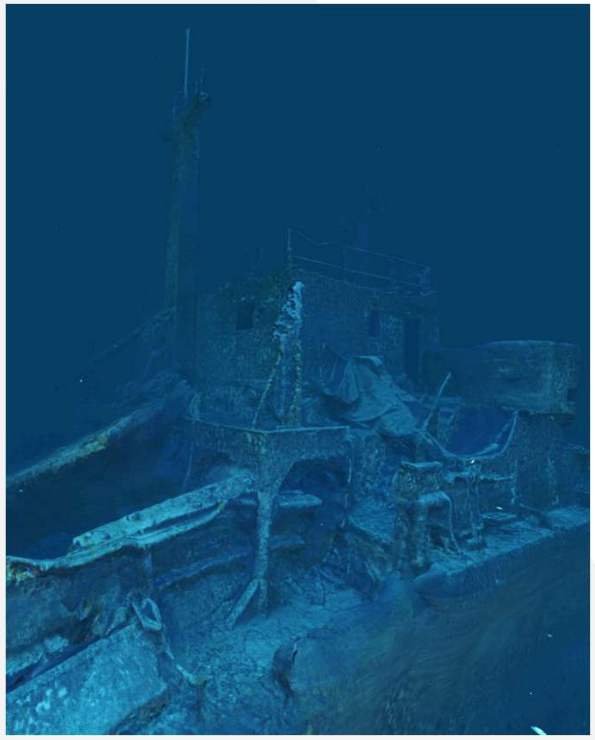




FACTORS OF INFLUENCE:

- Local geometry of ensonification
- Roughness at a scale comparable to the wavelength
- Intrinsic properties

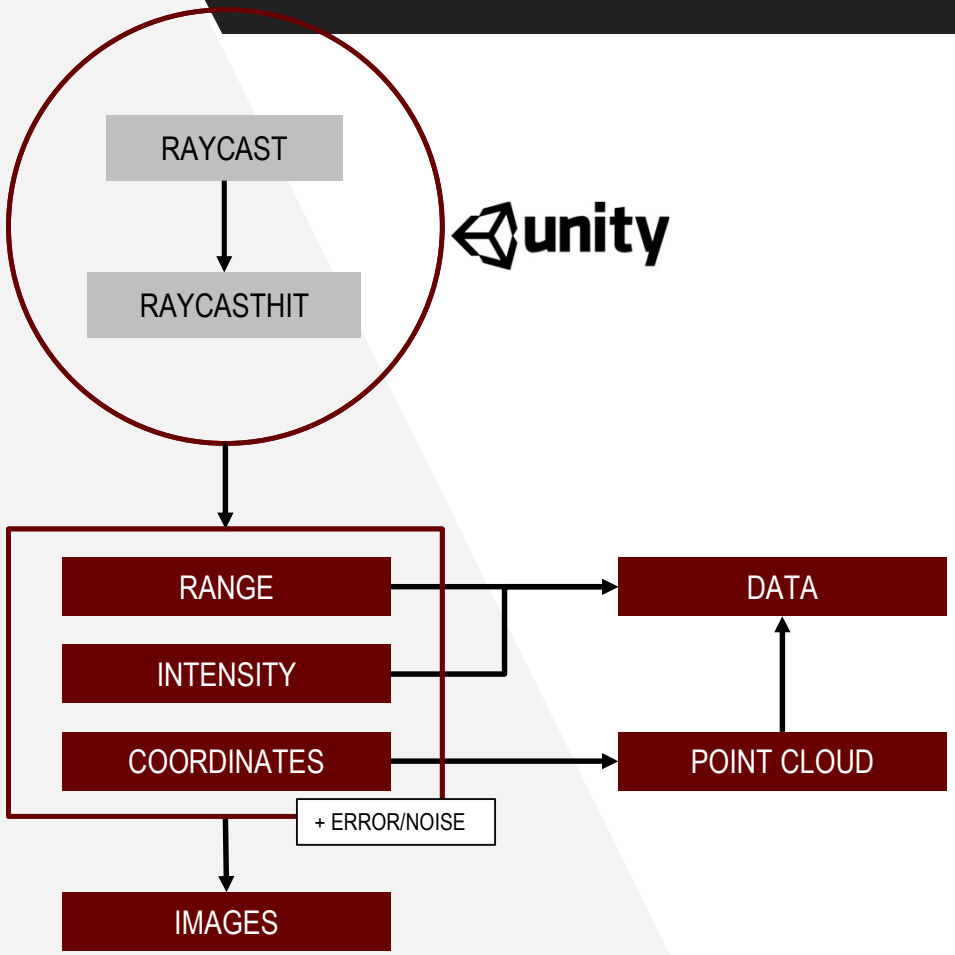
MBES MODELING APPROACH – TRANSLATION



REALISTIC 3D GRAPHICS
PHYSICS SIMULATION
SCRIPTING CAPABILITIES

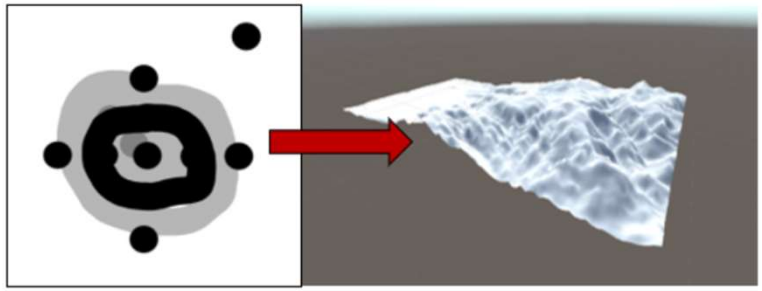
COST EFFICIENCY
SCENARIO EXPLORATION
DATA GENERATION AND VALIDATION
ALGORITHM DEVELOPMENT AND TESTING
VISUALIZATION AND ANALYSIS

MBES MODELING APPROACH – TRANSLATION



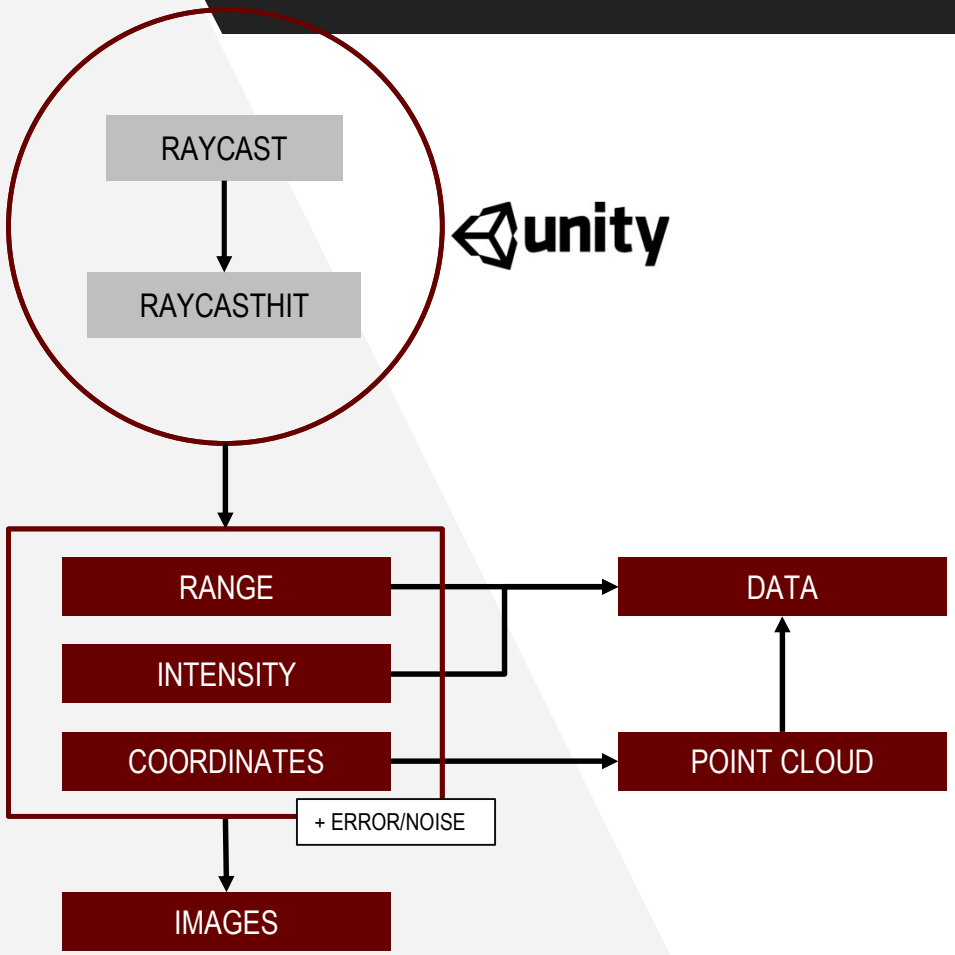
For each raycast of the swath, the following factors have been considered:

- Intensity**,** which varies based on **the angle of incidence** and **the distance** between the receiver and the target (Lambert's law).
- The dependency of the **reflected signal on the material** of the object that was struck.
- The phenomenon of the **recorded distance**, which is influenced by the angle of the beam.



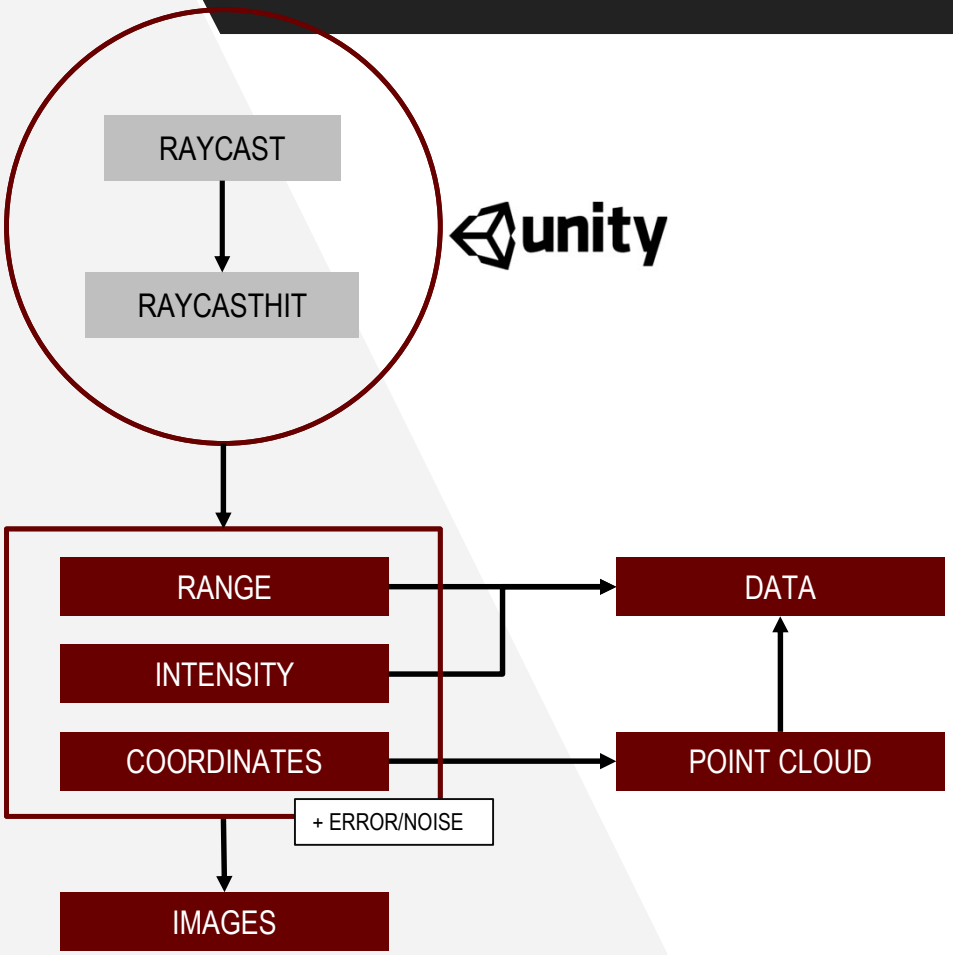
Example of Reflection Map in Unity3D to simulate the behavior of reflected signal on the material.

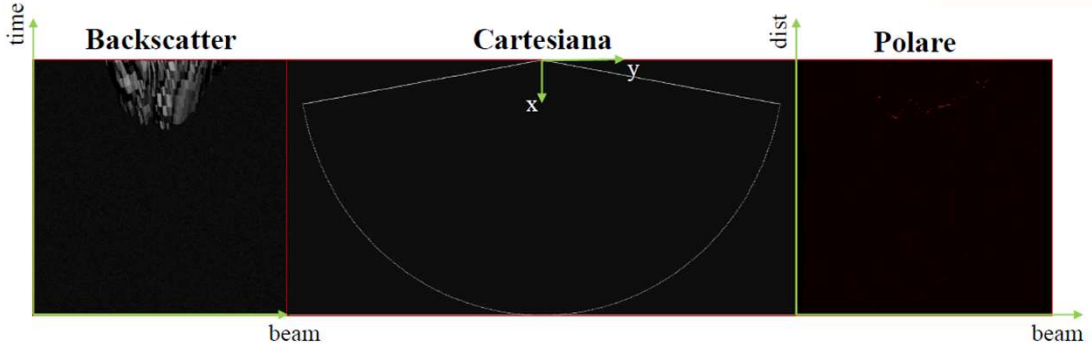
MBES MODELING APPROACH – TRANSLATION

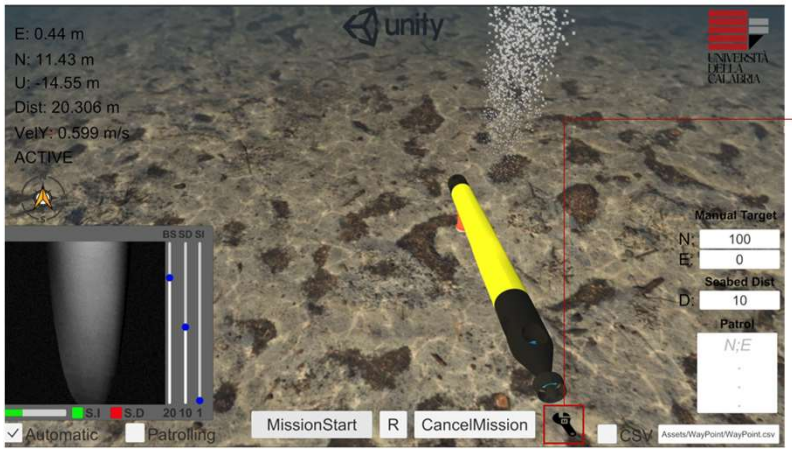


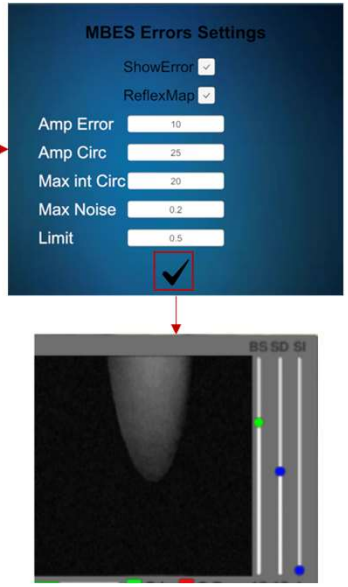
PARAMETER	DESCRIPTION
Beam Number	The number of Raycasts
Slant Range	The maximum acquisition distance
Min Distance	The minimum acquisition distance
Fan Open	The angular aperture of the sensor beam, expressed in sexagesimal degrees
Ping Rate	The operating frequency of the sensor provided as input to the EnoughTimePassed function to manage the moment when the RaycastReader (acquisition) is called
Diffuse	A boolean variable that allows enabling material dependency to test the effects due to geometric factors alone or considering the composition of the seafloor
Send Msg	A boolean variable to activate the SendPointCloudMsg function and receive the geolocation of points from ROS

MBES MODELING APPROACH – TRANSLATION





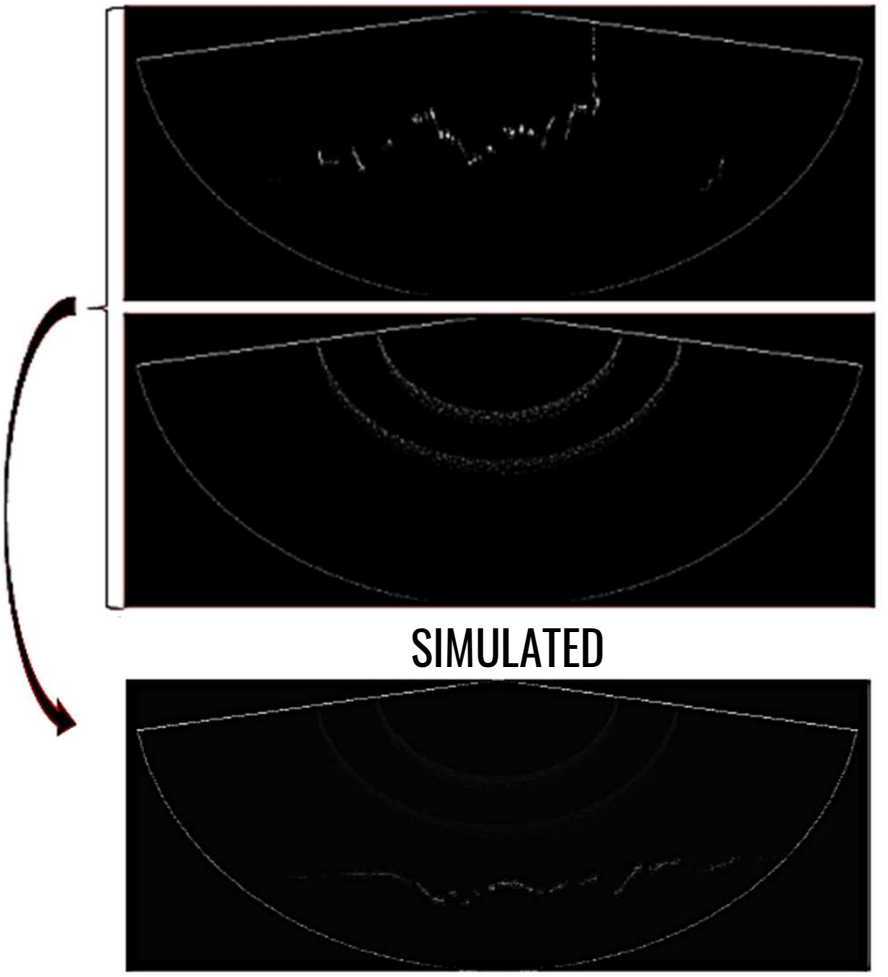




MBES MODELING APPROACH – V&V

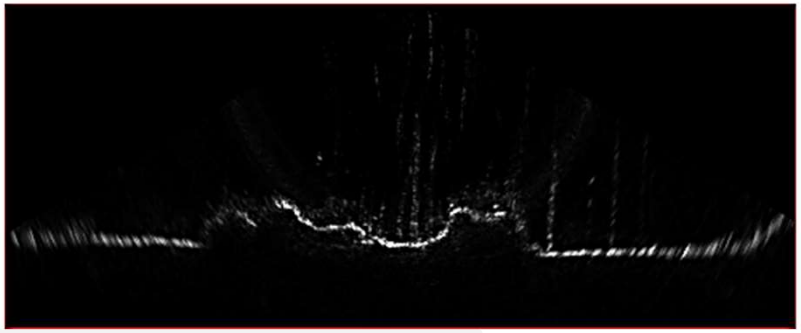
NON-IDEALITIES ON THE IMAGE

- Noise on the target
- Circular artifact around the emission point



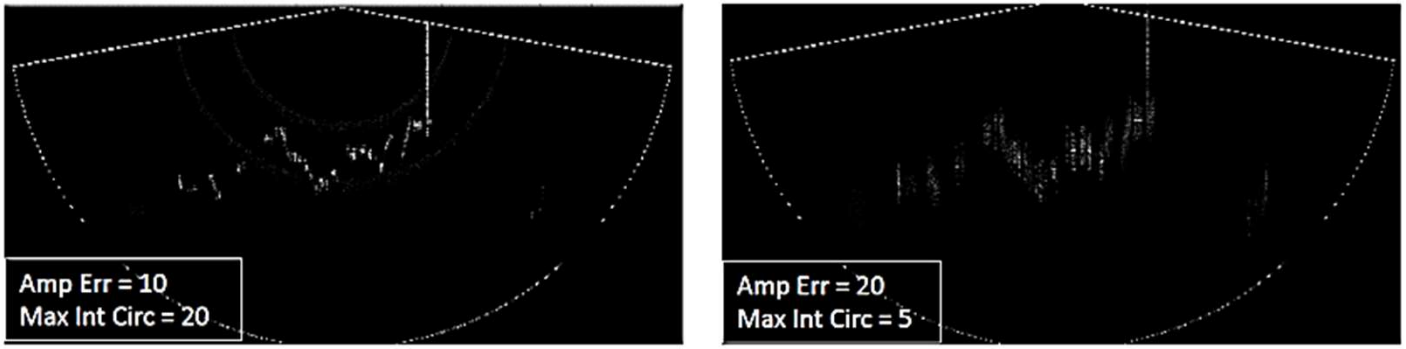
SIMULATED

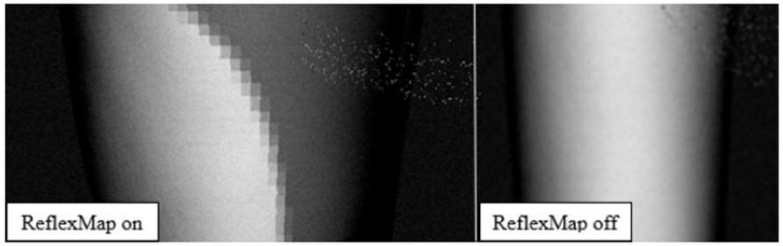
REFERENCE



MBES MODELING APPROACH – V&V

SIMULATED





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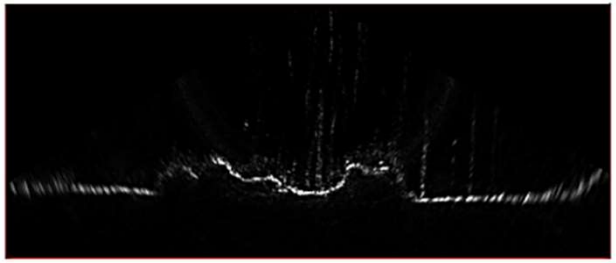

AI MODULE – RESULTS

- Real-to-Synthetic dataset ratio 1:3

What we expected

TRAINING DATASET	VALIDATION DATASET	ACCURACY
SYNTHETIC	SYNTHETIC	High (e.g., 90%+)
SYNTHETIC	REAL-WORLD	Moderate to High (70-90%)
REAL-WORLD	REAL-WORLD	Moderate to High (70-90%)
PRE-TRAINING WITH SYNTHETIC, FINE-TUNING WITH REAL-WORLD	**REAL-WORLD**	**High (e.g., >90%)**

Has to be considered:

- Real-world dataset size
- Generalization of synthetic data
- Fine-tuning

Results we achieved:

DATASET	ACCURACY	
	SYNTHETIC	REAL
SYNTHETIC	**0.95**	**0.62**
REAL	**-**	**0.85**
MIXED	**-**	**0.92**

Thanks for your attention!

www.3dresearch.it

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