Digital twins: Promoting sustainable tourism and monitoring of marine environment

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Digital twins offer multifaceted applications particularly in promoting sustainable diving tourism practices, monitoring marine ecosystems and critical coastal infrastructure, but also as a valuable tool for public awareness. In recent years, there has been a noticeable increase in the application of photogrammetry for creating digital twins, not only for the terrestrial but also marine environments. Cyprus is a popular holiday destination, given its warmer weather and crystal-clear waters year-round. This attracts numerous divers who come to explore the dynamic dive sites around Cyprus. We aim to provide guided, interactive three-dimensional (3D) reconstructions of the most important dive sites with valuable information for divers to make safe and informed dive plans. The dive sites include natural reefs, renowned shipwrecks like the 'Zenobia' and underwater museums like 'MUSAN'.

A notable advantage of photogrammetry is its ability to provide millimetric scale accuracy both at colony and reef-scales. This technology is also leveraged in ongoing restoration efforts of Mediterranean endemic scleractinian coral, *Cladocora caespitosa,* as part of 'EFFECTIVE' a 4-year HORIZON Europe project that has the mission to protect and restore the EU's Mediterranean Blue Natural Capital. Climate change (i.e., marine heatwaves, intense wind-storms) and other anthropogenic stressors have significantly impacted the populations of *C. caespitosa* around Cyprus, necessitating active restoration strategies. To quantify the effectiveness of the restoration efforts, seasonal data is collected for both native colonies and coral nubbins placed on our state-of-the-art floating coral nurseries to monitor the temporal changes in terms of growth and mortality. Three-dimensional reconstructions are generated using hundreds of high-resolution images to accurately measure these changes. Additionally, the data collected to create the digital twins of the dive-sites serves as a baseline for estimating benthic cover and topographic changes over time.

Digital twins, like the ones used in this project, provide valuable information for making informed decisions, both for conservation/management and recreational purposes. Their visually appealing data output also makes them effective tools for public awareness. We are exploring immersive virtual reality (VR) experiences to "bring the ocean to users," using emerging algorithms like 3D gaussian splatting to create hyper-realistic VR experiences. We aim to engage citizens and enhance public awareness for marine conservation.

Keywords
Photogrammetry; Shallow Water Reefs; Diving Tourism; Coral Restoration; Ecological Monitoring; Virtual-Reality (VR)