

Morecambe Area Gaming Environment (MAGE): An Applied Case Study for Coastal Futures and Adaptations

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Abstract

Large regions and coastal urban communities face significant climate-related risks, including coastal and river flooding, inundations, and sea-level rise. However, long-term predictions of coastal flooding, coastal change, and associated risks involve uncertainties that are difficult to communicate to those affected. This, in turn, can hinder the adaptation of coastal communities to future changes. In our proof-of-concept case study, MAGE (Morecambe Area Gaming Environment), we developed five research tools to enhance engagement between local government and local residents on coastal change, its effects on settlements, and the existing shoreline management plan (SMP) policies. First, we created an open community mapping platform to gather voluntary geographic information (VGI). Second, we developed a mini tabletop game for KS3 Geography for secondary schools. Third, a serious tabletop game that simulates coastal systems and places in North-West UK, playing with communities and schools as a precursor to informing and developing the fourth tool: a sandbox computing system. The portable digital chessboard sandbox that visualises thousands of what-if scenarios in 2055 and 2105 uses Lancaster University’s high-end computing (HEC) resources and a VR experience (our fifth tool). This article concentrates on the decision table, using numerical coastal models, GIS, and algorithms ported to a game engine; the MAGE system features interactive play pieces that the public can move in a 3D environment. Users simulate future climate scenarios for their area and choose interventions and mitigation measures for coastal flooding or change, whether nature-based solutions or hard engineering. Research results identified a specific communication need enabled by spatial computing, allowing communities to interact within the planning decision space and provide rich experiences to mitigate climate change. The MAGE prototype and case study serve as both an educational and participatory tool for coastal communities to map adaptation pathways for transitions between SMP policies. MAGE, as a situated planning artefact, effectively bridges large-scale coastal territories—both rural and urban—to plan for coastal futures.

Keywords

adaptation pathways; climate resilience; coastal management; coastal modeling; regional planning; spatial computing

1. Introduction

The etymons of “mage”—French, *mage*; Latin, *magus*—“constitute a [person]...of exceptional wisdom and learning” (Mage, n.d.). Could models, simulations, and game engines constitute an equivalent knowledgeable function to mediate, forecast, and provide information—a [system] “of exceptional wisdom and learning”. How would such a system function? What would be its agency? How could spatial computing contribute to knowledge formation and decision-making in a rigorous way, be transparent in uncertainty, and actively involve a range of communities and stakeholders? These constructions and research questions formed the basis of the double acronym MAGE (Morecambe Area Gaming Environment), which explored coastal management options in collaboration with coastal communities across North-West UK. This project is part of the larger Our Future Coast project, led by Wyre Council and funded by the Environment Agency and the Department for Environment, Food and Rural Affairs (DEFRA), UK.

Coastal management planning in England and Wales is based on shoreline management plans (SMPs), a policy framework that addresses the risks of coastal change along stretches of coastline over the short (0 to 20 years), medium (20 to 50 years), and long term (50 to 100 years), or three epochs. There are four policy options in SMPs: hold the line, advance the line, managed realignment, and no active intervention. SMPs are non-statutory plans intended to inform strategic planning, including the UK national planning policy framework (NPPF) on sustainable development in coastal areas. They also provide a basis for determining coastal change management areas (CCMAs) for planning decisions by local planning authorities. SMPs consider coastal processes, historic settlements, the built environment, and the natural environment in combination. Thus, SMPs address sustainable development goals SDG 11, 13, and 14 in primary urban areas, small towns and villages, and urban and rural communities. As part of the challenge, the wider Our Future Coast team aims to address the issues of unsustainable coastal protection by working with nature, as protecting coastal communities from flooding and erosion through hard-engineering structures becomes unsustainable due to rising costs and environmental impacts (Stojanovic, 2025); working with nature approaches are becoming a viable alternative. However, these approaches still have low social acceptance (Apine & Stojanovic, 2026) and require raising awareness and actively engaging communities to appreciate their wider benefits; a game-based method is utilised. MAGE supports this ambition to promote nature-based solutions through gameplay and decision support.

For this thematic issue, this article explores broader coastal and territorial practices of participation through a range of game-based methods, engaging communities in examining climate adaptation in response to climate disruptions. As a broad research challenge, coastal communities are on the front line of the climate challenge. It is not always possible to protect the whole coast with hard rock and concrete; there are not enough resources, and there is no good long-term solution. Many communities around the UK coastline will experience policy transitions in the coming decades, whether from holding the line to managed realignment or to no active interventions. This will require engagement with local communities to raise awareness of coastal changes across a wide range of urban and rural settlements, as well as co-developing adaptation

pathways with affected communities to support the transition from areas impacted by coastal erosion and associated risks (e.g., the Coastal Transition Acceleration Programme; see Environment Agency, 2026). These drivers are embedded in MAGE's game development and purpose.

Methods for visualising and communicating coastal change have appeared in many different forms, including tabletop games and digital game engines. A games publisher, Asmodee, claims that 30% of adults in the UK regularly play board games and that 26% play at least once a week, making tabletop games a key, accessible medium (Asmodee, 2025). In digital games, coastal applications include the Rising Tides project in Morecambe Bay, delivered via an immersive Igloo dome (Sairo Studios, 2023). Additionally, game engines are in ongoing use with the Environmental Protection Agency, Ireland, through digital twin approaches (Shakespeare & Stubbs, 2024; Strannegård, 2022; Strannegård, et al., 2023), and marine spatial planning challenge (Breda University of Applied Sciences, 2011) and engagement tools such as CoastCraft, a Minecraft education experience in Cornwall, developed in the Making Space for Sand project (CoastCraft, 2025). "Serious games," a term coined by Clark C. Abt, are defined as games with purpose, which are game processes used to explore questions and scientific viewpoints in various fields, including planning and government (Abt, 1970, p. 10). Serious games also appear to facilitate policy interventions and decision-making in areas such as urban mobility (Käyhkö et al., 2025), local planning (Cureton et al., 2026), and climate adaptation pathways planning (Sommerauer et al., 2026), defined as "sequences of actions that can be implemented progressively, depending on how the future unfolds, and on the development of knowledge and stakeholder preferences" (Werners et al., 2021, p. 371).

Adaptation-focused serious games and role-play simulations are used as interactive and experiential forms of engagement to build community readiness, communicate climate change, foster collaborative capacity, and involve stakeholders in adaptation pathway processes, including in flood risk management (e.g., Blackett et al., 2022; Kelly & Kelly, 2023; Nabong & Opdyke, 2024). Games typically place participants in realistic yet fabricated scenarios to understand the uncertainties, perspectives, interests, and responsibilities involved in complex decision-making processes (Kelly & Kelly, 2023; Rumore et al., 2016; Sommerauer et al., 2026). One of the most widely publicised games is the New England Climate Adaptation Project (NECAP) in the USA, which developed role-play simulations for four fictional towns—each linked to climate projections for a real-life locality (Rumore et al., 2016). Findings from NECAP and the wider literature highlight the value of adaptation role-play simulations and serious games for engaging wider stakeholders, building adaptive responsibility, and promoting social learning (Flood et al., 2018; Forrest et al., 2022; Rumore et al., 2016).

Building on the state of the art in community engagement, numerical coastal models, and SMPs, MAGE gaming and simulation environments are designed to visualise future climate uncertainty and facilitate participatory, local, and co-created approaches. Visualisation, co-creation, and coastal management strategy are intrinsically intertwined (Feagan et al., 2025; Kim et al., 2024; Ranson et al., 2024; Wolff et al., 2025; Yang et al., 2024). For this article, MAGE's spatial computing, in particular its digital chessboard, is aligned with augmented sandboxes that have a longer pedigree, such as JBA Trust's augmented reality sandbox created in 2020, which has hand gesture controls to demonstrate water movement through varying topography, the MIT's City Scope augmented platform for urban planning alongside agent-based models, such as Netlogo or GAMMA (Taillandier et al., 2019), and the use of serious games via augmented sandboxes for river resource management (Haan, 2018).

2. Structure

This article provides an overview of five tools developed as part of MAGE. However, this article focuses on the 4th tool: a digital chessboard sandbox that serves as a learning system to engage stakeholders in the decision space of coastal adaptation planning.

The tools are the following:

1. A mobile app for voluntary geographic information (VGI) and public coastal perceptions.
2. MAGE mini game for KS3 Geography as part of the Morecambe Bay Curriculum co-designed with Richard Spencer at Bowland High School, UK, covering SMPs, coastal interventions, and coastal adaptation pathways. MAGE mini includes supporting fieldwork and lesson plans.
3. A large-scale tabletop game of the North-West coast and game system developed after the Environment Agency's policy and SMPs (playable up to 20 people and running for more than 45 minutes).
4. MAGE digital chessboard sandbox for decision-making.
5. A virtual reality experience of OFC sites with sound actions and high-resolution drone-derived models and GIS data based on the main MAGE system.

VGI was used as the basis for creating the Map.Social web and mobile app to gather community viewpoints. A tabletop game was created to consider the SMP policy and engage communities and foster dialogue in this process (3rd tool; Cureton, 2025). The tabletop game works as a precursor for the computational thinking developed with the 4th tool, the MAGE digital chessboard, including its design, modelling, pipeline, and interaction methodology. Figure 1 shows the tools and configurations in relation to audiences and outcomes. This intentional flexibility in tooling is the result of diverse audiences, differing goals, and decision-support tasks. Figure 2 demonstrates the numbered tools.

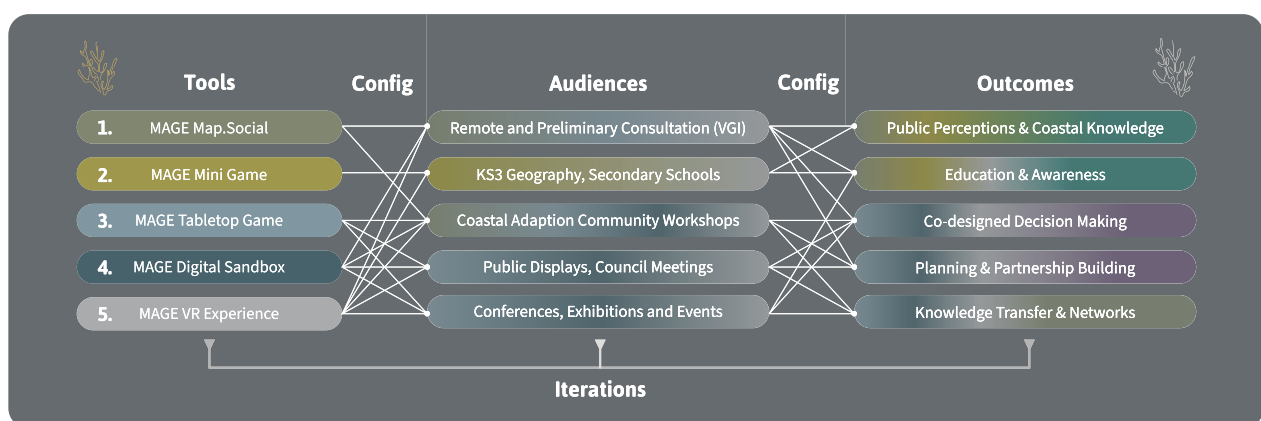


Figure 1. MAGE tools knowledge graph, the varying configurations and deployments, types of audiences, and configurations for outcomes.

The configuration and tool selection depend on in-situ local conditions, co-design workshop durations, the number of stakeholders, the levels of decision-making (from community to local government), and the required outcomes, ranging from educational awareness to specific coastal decision outputs via MAGE. This flexibility is intentionally designed to accommodate the range of stakeholders and the iterative nature of the collaborative participation framework.

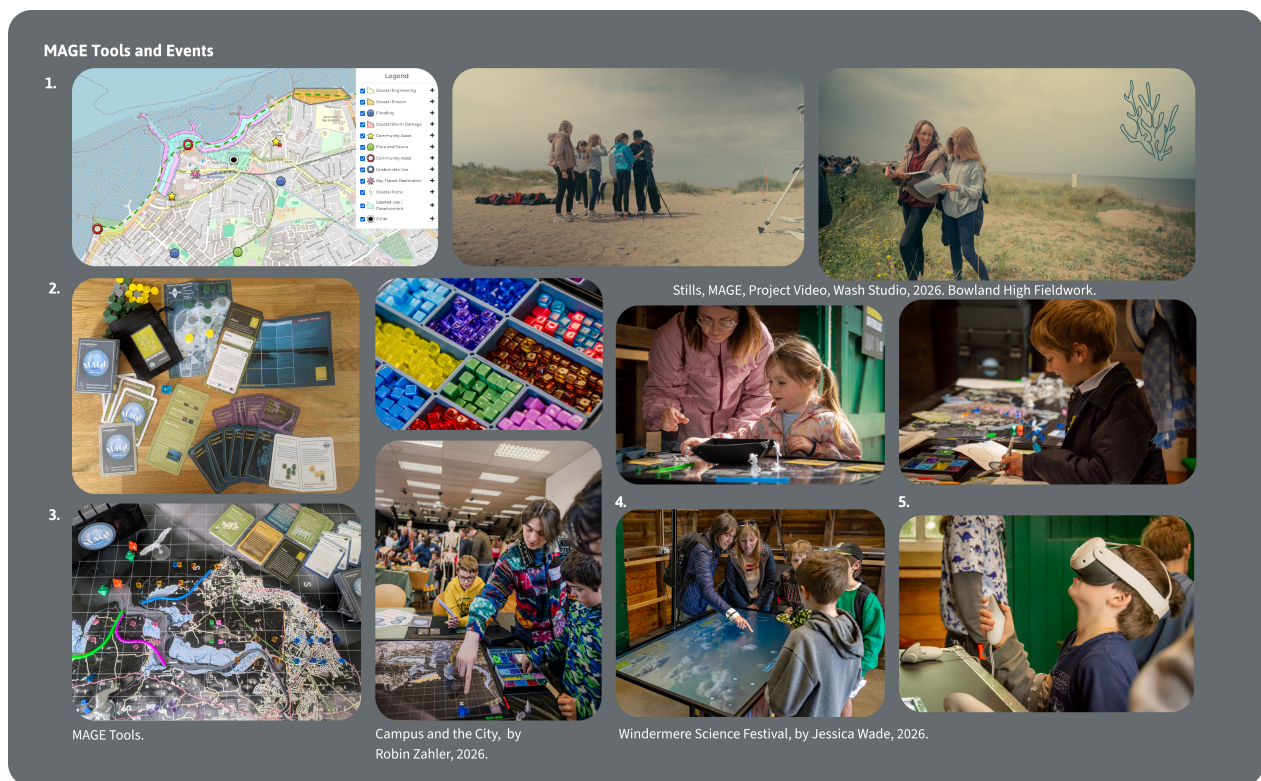


Figure 2. Image of 5x MAGE tools, including the VGI app (1), ESRI web platform (2), MAGE mini game (3), MAGE tabletop game and (4) MAGE digital sandbox, and (5) MAGE VR experience from various project events (5). Photography by Robin Zahler, Jessica Wade, and Wash Studio.

The methodology of the 4th tool is discussed at length in terms of spatial computing, as this uniquely combines numerical coastal models with a visual pipeline implemented in a game engine to simulate morphological change, with GIS data on buildings and vegetation forming a large, varied visualisation of flood risk in a portable, interactive sandbox with playable physical pieces. This aspect is one core achievement of the research to date, and has not been achieved in this research space.

Finally, the article discusses the results and limitations and identifies the potential replicability of the digital chessboard and its relationship with coastal adaptation strategies, key approaches to coastal resilience. The article, however, does not discuss proof-of-concept testing and the extended results of coastal adaptation workshops in depth, as this warrants a standalone article with detailed reporting and extensive analysis of gameplay and the resulting community decisions. Instead, it focuses on the schema of spatial computing and the detailed construction process that provides socio-technical approaches.

3. MAGE Tools

Using Houseal Lavigne's Map.Social platform, an app built on ESRI ArcGIS Online, a VGI interface was created for web and mobile devices via anonymous (guest) login to label the coastline from Liverpool to Millom. The base map includes one base layer and five toggleable layers:

1. Base layer: DEFRA, Environment Agency OGL Data—SurfZone DEM 2019 (2m).

2. National coastal erosion risk mapping data (NCERMS), which projects areas at risk of erosion for two time periods: medium term (up to 2055) and long term (up to 2105).
3. DEFRA, Environment Agency OGL Data—Spatial flood defences including standardised attributes.
4. DEFRA, Environment Agency OGL Data—Saltmarsh Extents 2016–2019.
5. Marine conservation zones—Natural England.
6. Sites of special scientific interest—Natural England.

The data includes two management scenarios: SMPs delivered and “no future intervention.” Three climate scenarios are also used: present-day climate (as of 2020), higher central allowance, and upper-end allowance. The higher and upper percentile allowances use sea-level rise data from UKCP18 RCP8.5 at the 70th and 95th percentiles to model extreme climate risks (Environment Agency, 2024). Let’s Map Our Future Coast features 12 annotation layers for public labelling, including photo uploads, with all annotations and anonymous media exportable as CSV or PDF for reporting. The platform is designed to capture perceptive values, observations, and local knowledge. The platform is also designed as one of the five MAGE tools within wider coastal adaptation projects, staged as a framing device and starter for discussions and early workshop phases to record local viewpoints (see Figure 1).

The MAGE tabletop game was designed for public dialogue. A game system was designed to translate policy and management practices into a strategic, interactive game while considering the accessibility and popularity of tabletop games. Such a process would allow consideration of the range of “gameplay” limitations and inform the development of inputs and parameters, prior to dedicating resources for spatial computing in the digital chessboard (the 4th tool). MAGE has been played at the boardroom level, in academia, and at youth-focused festivals, with n. 1800 participants across seven events at the time of writing, providing educational enrichment to an area with a limited understanding of SMPs and coastal management approaches. The game, the 2nd tool, consists of large A1, 1:25,000-scale map gameboards that connect to form the NW, UK extent, game characters, game tokens, and a card deck. Players must strategise to complete scenarios involving storm events, flooding, rapid urbanisation, and the placement of defences, among other actions (flexible strings represent defences in Figure 2). Players interact with one another and discuss community values, strategies, and local observations, with an expected gameplay time of 45 minutes to 1.5 hours.

The first iteration of the game required much clearer win conditions and clarity on game rules and mechanics, which provided a useful framework and a further iteration of the tabletop game for the framing of the digital chessboard, as did an additional requirement for the 2nd tool—the short-form game for school settings, called MAGE-mini (15–30 mins), played with 140 children in KS3 Geography. This early-stage tool provided valuable data to frame what a digital sandbox requires in terms of interaction and to specify future computational development of the 4th tool (Liapis & Denisova, 2023). Capturing dialogue through gameplay and game decisions as an experience also requires a robust computational mechanism. Both tools have been deployed together in engagement events. However, the 4th tool has been specifically embedded in coastal adaptation pathway workshops. Gameplay results also vary between analogue and digital approaches. Results can vary by participant cohesion, enjoyment, game motivations, and conditions, and can be wildly affected by the resulting qualitative and quantitative gameplay data. Each has challenges in capturing gameplay decisions and motivation for play (Garcia-Soriano et al., 2025). In addition, MAGE and its digital equivalent are not connected as analogue and digital devices, unlike many blurred game systems that translate game flows between the two media in augmented experiences (Han et al., 2026).

predictions are +0.24m in 2050 and +0.65m in 2100, with tidal predictions at +0.06m and +0.15m under the RCP 8.5 projection, and the area has a high-high risk classification used by policymakers for understanding the risks for climate mitigation, adaption, and resilience (Arnell et al., 2025; Bricheno & Rulent, 2025a, 2025b, 2025c).

Coastal change is usually simulated by coastal area morphodynamic modelling software that can predict changes at various spatial and temporal resolutions. These models consist of hydrodynamic modules such as wave transformation and nearshore current models, a sediment transport module, a morphological change module, and may include coastal structures. These nearshore models are typically informed by ocean models and can include open-coast, estuarine, and riverine environments. Software includes CoastalFOAM, MIKE21, Delft3D-FM, XBeach, among others, and results are often post-processed in ESRI ArcGIS and MATLAB.

MAGE used SMP policies as frames to bridge numerical model outputs in a dynamic interactive environment and was guided by modelling principles: (Environment Agency, 2019, 2025). Our research development considered three broad issues from the decision-making matrix for suitability: (a) expected coastal trends, (b) management impacts at the site, and (c) nearby management impacts and climate change impacts (see Environment Agency, 2019, p. iv). Modelling aspects ultimately consider a range of interventions based on the four coastal management approaches set out in the SMP policies:

1. Hold the line—maintenance of artificial defences.
2. Advance the line—new seaward defences and land reclamation.
3. Managed realignment—natural repositioning of shoreline.
4. No active intervention—no planned investment for the zone.

Three distinct game zones, Unreal Engine game setups (or sites), were established and will later be expanded to eight sites across the Northwest Coast in early 2027 as part of the Our Future Coast programme. The proof of concept is structured in four sub-sections: (a) data assimilation, (b) modelling phases enacted, (c) vision pipelines established, and (d) custom user interface development. For example, one gamezone, Walney Island, a landmass east of the Walney Channel, shelters a heavily industrialised town, Barrow-in-Furness, and the Port of Barrow, a significant UK defence asset for nuclear submarine construction (Figure 4). Beyond a 100-year scope of study, in 2014, unmanaged erosion could form channels cutting across the island with impact to the port, among many other challenges, including large-scale risk to property (Barrow Borough Council, 2014, p. 9). Another game zone site, Hest Bank above Morecambe and below Polton le Fylde, features saltmarsh requiring restoration and a critical embankment that hosts the West Coast Mainline railway line (London to Glasgow) infrastructure and housing, both of which are prone to long-term flood and erosion risks. Both game zones indicate varying challenges, community needs for resilience, and climatic effects.

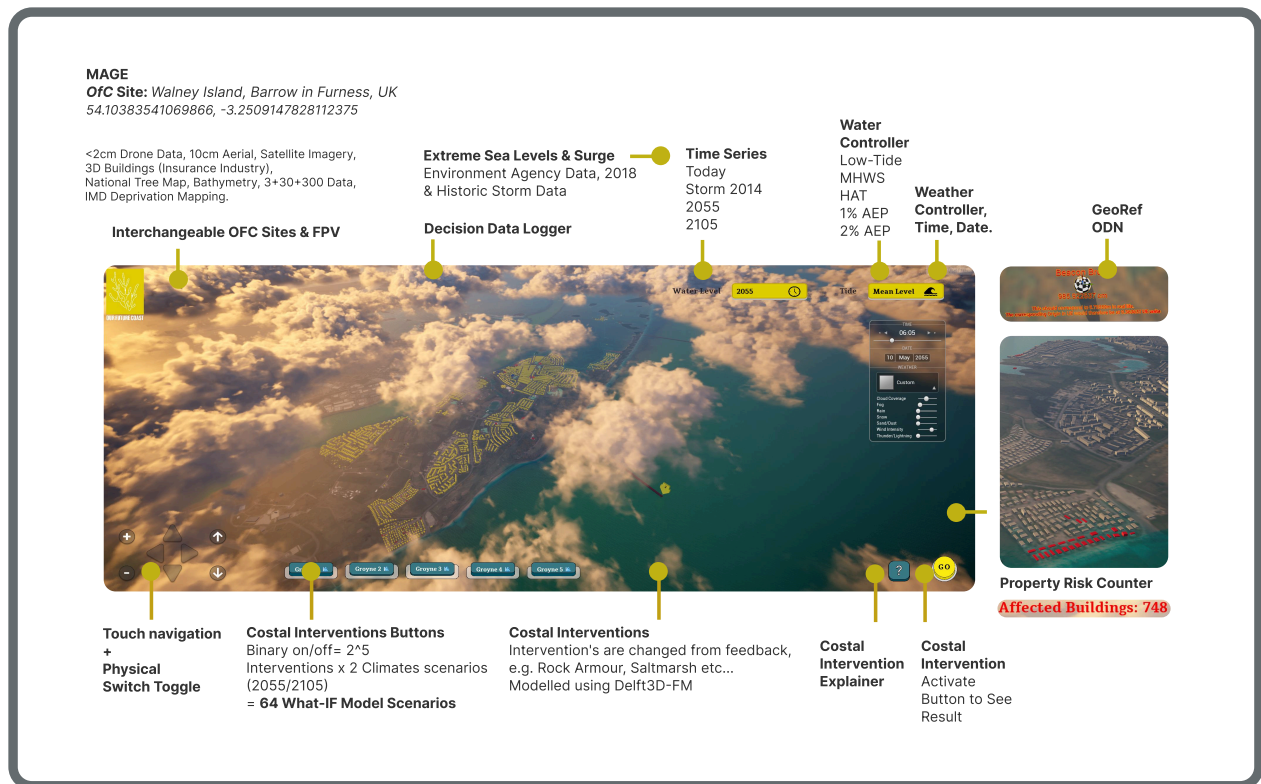


Figure 4. MAGE game HUD, one “game zone” environment, and interventions built, Walney Island, Cumbria, UK.

5. MAGE Data

Several monitoring instruments and supporting data were also available for MAGE, including radar, buoys, tidal predictions, existing commissioned coastal models, and a variety of local authority GIS data, which were incorporated into MAGE and computed in a variety of software, including LECIA Cyclone Register360, DJI Terra and Modify, ESRI ArcGIS, ESRI CityEngine and Unreal Engine. Data incorporated included the UK Tide Gauge Network, which forms part of the National Tidal & Sea Level Facility, National Oceanography Centre, National Network of Regional Coastal Monitoring Programmes, data catalogue, EDINA, and Environment Agency multibeam 50 cm bathymetry and FCERM near-shore LiDAR surveyed by Andrew Martin (Sefton Council). Additional data included National Tree Map data, which consists of height, location, and canopy/crown extent of trees; the 3+30+300 dataset, which uses proximity to natural environments as a health indicator; and Verisk 3D buildings used in property insurance, underwriting, and risk management, covering 46 attributes such as EPC rating, age, dwelling type, etc. UAVs have a unique role in coastal adaptation and monitoring (Tadić et al., 2022). For MAGE, repeat precision drone surveys were conducted at several sites to map intertidal zones using Structure from Motion (SfM) and Gaussian splatting post-processing. Surveys were conducted using Real Time Kinematic (RTK) multi-station and ground control points (GCPs > 5) to produce <1.5–2.5cm GSD resolution maps by the authors, with flight design depending on site restrictions, such as adapting mitigations for site of special scientific interest (SSSI) areas. Such a combination of data would create a 3D environment in which future scenarios can be observed and interventions added to the “chessboard.” Post-processed drone surveys were exported as OBJ file types for

integration via MetaQuest 3, VR headsets, PICO4 HMD, and X-Real Aura Glasses, via ESRI ArcGIS Online for initial short community experiences of virtual sites and the development of the 5th tool.

6. MAGE Modeling

Utilising Lancaster University high-end computing (HEC) resources, multiple model runs were computed using Delft3D FM and a unique output code naming convention and temporal aspect number. Using Delft3D-FM, its engine allows users to apply unstructured grids that efficiently capture complex coastlines and bathymetry while maintaining computational performance. The hydrodynamic module solves the shallow-water equations to model water levels, currents, storm surges, and tidal flows with high accuracy, making it suitable for flood-risk assessment and coastal-engineering studies. Complementing this, the integrated wave module (based on advanced spectral wave formulations) simulates wave generation, propagation, refraction, diffraction, and wave-current interaction. Together, the hydrodynamic and wave modules provide a fully coupled framework that can represent complex physical processes in dynamic marine and freshwater environments, supporting both research applications and practical engineering design, which provides utility for MAGE interactions. For each MAGE “gamezone” (Figure 4), a new simulation is created with its own specific mesh or grid. The game zone of interest is determined in consultation with stakeholders, which in turn informs the numerical model’s boundary. Several possible coastal protection interventions have been previously agreed upon, and their impacts are then simulated in the numerical model through iterations.

To support grid generation, the coastline polyline was imported into the GIS environment. The computational grid (mesh) was constructed in accordance with the defined coastline of the game zone. Bathymetric (bed-level) data were incorporated into the model, and selected intervention measures were implemented using the available modelling capabilities within the flow module. The wave and flow simulations were initially run separately. The wave model was run on a structured grid, using appropriate boundary conditions. The hydrodynamics were simulated on an unstructured grid utilising the Delft3D-FM framework. Boundary conditions were specified to simulate tidal water-level variations along the model domain’s open boundaries. The use of an unstructured mesh enabled spatial refinement in areas of particular interest identified during the stakeholder consultation phase by increasing the grid point density in these locations. The spatial extent of the flow model domain was nested within the larger wave model domain, enabling wave propagation to be simulated prior to interaction with the hydrodynamic processes resolved by the flow model.

Once both the wave model and the Flexible Mesh flow model were verified to function independently as intended, they were coupled to create an integrated model. The integrated model was then exported, generating a set of files in various formats, including netCDF.

7. MAGE Vision Pipeline: Mesh Generation and Transformation

Translating numerical coastal model outputs into a real-time, interactive game-engine environment was one of the most technically demanding stages of the MAGE pipeline and a core contribution to this field in simulating natural coastal processes and housing and urban risk. Delft3D-FM produces simulation results on an unstructured flexible mesh: a computational grid composed of irregular polygonal cells whose resolution

varies spatially to concentrate computational effort where it is most needed (e.g., near coastal structures, tidal inlets, and regions of morphological interest). Each simulation run is exported. However, the unstructured nature of the Delft3D-FM mesh, in which individual computational cells have no fixed rectilinear adjacency, poses a fundamental challenge for raster-based visualisation and integration into game engines, both of which typically operate on regular grids.

The transformation pipeline begins by extracting face-centred mesh coordinates and associated hydrodynamic variables from the netCDF outputs. For each run, the two-dimensional face positions define the spatial location of each computational cell centroid in projected coordinates (EPSG:3857, Web Mercator). Physical quantities of interest are derived from variables such as water surface elevation, water depth, and sediment bed level. Prior to any spatial processing, valid timesteps are identified by scanning each variable's time dimension for non-NaN (not a number) entries; incomplete outputs, arising from spin-up periods, boundary effects, or early termination, are discarded. Cells outside the active domain are masked to prevent propagation of invalid values.

Coordinate reference system (CRS) alignment is a prerequisite for integration with the wider MAGE geospatial dataset. Delft3D-FM outputs must be reconciled with the British National Grid (EPSG:27700) used by the Environment Agency LiDAR Digital Terrain Model (DTM) tiles and the aerial imagery baseline. CRS metadata is extracted directly from the netCDF files by inspecting CF-Conventions grid-mapping variables, coordinate-variable attributes, and global dataset metadata. Where reprojection is required, the unstructured point set of mesh face centroids is transformed prior to interpolation, ensuring that all subsequent spatial operations occur in a consistent projected coordinate frame with metrically meaningful distances and extents.

The central transformation step interpolates irregularly sampled model outputs onto a regular rectilinear grid. This is implemented via scattered-data interpolation using linear triangulation: A Delaunay triangulation is constructed over valid mesh centroids, and values are linearly interpolated within each triangle to evaluate the field at target grid nodes. The target grid extent and resolution are defined by the intersection of the Delft3D-FM model domain with the LiDAR DTM mosaic footprint, ensuring that interpolated hydrodynamic layers and terrain elevation share a common spatial support. The resulting rasters represent hydrodynamic variables at a resolution that balances visual fidelity against computational tractability for real-time rendering.

Following interpolation, hydrodynamic grids are co-registered with the LiDAR DTM mosaic. The terrain baseline is assembled by stitching together multiple high-resolution LiDAR tiles that span the core MAGE study region. Both the interpolated model outputs and the DTM are warped to a common square raster using bilinear resampling, with dimensions selected to satisfy Unreal Engine Landscape resolution constraints (of the form $n = (2^p \times k) + 1$). Elevation values are then normalised to the full 16-bit unsigned integer range (0–65,535), encoding the study-area elevation span as a 16-bit grayscale heightmap. The heightmap is exported using a binary-accurate 16-bit pipeline to preserve sub-metre precision, avoiding quantisation artefacts associated with standard 8-bit image export.

In parallel, an 8-bit RGB aerial texture is generated by warping the aerial imagery baseline to the same spatial extent and resampling to a power-of-two resolution consistent with common game-engine texturing conventions. Pixels outside valid data coverage are filled to delineate no-data boundaries. Together, the

16-bit heightmap and the co-registered aerial texture form a georeferenced terrain asset pair. These assets are imported into Unreal Engine as Landscape Actors, thereby reconstructing a three-dimensional terrain surface onto which hydrodynamic outputs are subsequently rendered. This pipeline presents model-driven environmental dynamics as an interactive coastal simulation environment for MAGE participants.

Within Unreal, the model run dynamics and translation in the vision pipeline simulate a permutation. Some permutations affect housing and infrastructure stock, in which the Unreal water actor touches the structures and activates a numerical counter button. This action also activates and highlights affected structures through a visible change in colour code within the 3D environment, highlighting and building fabric affected in any scenario.

8. MAGE Interface

The user interface is implemented as an on-screen overlay within the Unreal Engine environment. The interface is organised into three control groups (a, b, c): (a) climate scenario controls are positioned in the upper-left corner to specify the scenario year used to visualise the simulation output; (b) a dropdown menu in the upper-right corner allows players to switch between game zones (i.e., different coastal locations); and (c) intervention controls are anchored along the lower edge of the screen, enabling rapid and repeatable selection of adaptation strategies. This layout distinguishes between contextual parameters (scenario year and location) and management actions (interventions), thereby clarifying how different inputs shape the simulation.

8.1. Scenario and Game Zone Selection (a)

The climate scenario control is presented as a two-state toggle corresponding to NCERMS scenarios 2055 and 2105. This toggle format frames climate futures as discrete, comparable temporal horizons that can be toggled quickly during exploration. Functionally, it separates temporal framing from the interventions that modify the coastal landscape, thus enabling a structured comparison: players can hold the intervention set constant while switching the climate scenario year to assess how the same intervention strategy performs under different climate conditions. Game zone selection is provided through a dropdown menu. Separating location selection from the intervention interface reinforces the conceptual distinction between where an intervention is applied and what intervention is chosen. Available interventions vary by location, reflecting site-specific coastal characteristics.

8.2. Intervention Selection (b)

Interventions are represented as a set of consistently styled buttons. The interface supports both single- and multi-selection logic, enabling players to apply a single intervention or explore combined strategies. This is important for coastal adaptation, where interventions are often deployed as portfolios rather than isolated actions, and where combined effects may yield outcomes different from those of each measure applied independently. To support recognition and reduce interaction effort, the intervention buttons are deliberately large and visually uniform, incorporating both text labels and icons. This design is intended as a real, pressable button to make it clear to players which intervention is taken. Interaction sound effects provide additional feedback, reinforcing that a selection has been made and supporting confident, iterative

exploration. Upon activation, interventions are 3D-labelled in the game zone, assisting cognition and observation of coastal dynamics. A separate, highly salient GO button is placed at the bottom-right to formalise the transition from configuration to execution. This two-stage interaction reduces accidental activation and clarifies when the system will commit the chosen scenario/intervention set to the simulation update.

8.3. Pop-Up Information Panels (c)

Selecting an intervention triggers a pop-up information panel that provides a concise explanation of the intervention and its classification as a strategy. These panels provide just-in-time interpretive support in accessible language, without requiring users to navigate to a separate help screen. They are semi-transparent so that the coastal scene remains visible, maintaining continuity of visual attention and reinforcing the primacy of landscape interpretation. A close button enables a smooth exploration cycle that encourages repeated testing and comparison: select → check meaning → close → run/compare.

Across these interface elements, the following four design considerations guided implementation. First, landscape visibility was prioritised by confining controls to screen edges and using semi-transparent overlays to avoid obscuring the simulation view. Second, stable control placement was used to reduce cognitive load and build familiarity across repeated testing cycles. Third, the interface structure supports structured comparison by allowing users to vary one dimension (year, zone, or intervention set) while holding others constant, with a clear separation between contextual parameters and interventions. Finally, error prevention and reversibility are supported through toggleable intervention selection, dismissible pop-ups, and the explicit execution step enabled by the GO button. MAGE provides complete temporal control across time, dates, and years, and features a controllable weather system for dynamic effects, including built-in sounds that enable slide-controller control of clouds, rain, thunder, fog, and many other elements.

9. Discussion

MAGE, a proof of concept spanning five digital tools, is an experiment informed by tabletop game design for spatial computing. MAGE is intended to serve as a discussion point in coastal adaptation workshops and to educate communities on SMP policies, facilitated by specialists during post-play discussions to explore the decisions and options made during play. Marine-based serious games have a number of precedents, such as Dilemma Game: The Wind at Sea (OLAMUR, 2025), adaptation decisions (NIWA, 2025), and climate risks for cities (CCA, 2015). The range of serious games provided parameters for framing, natural systems, reasoning and decision-making, and computational thinking around puzzles and logic (Parekh et al., 2021; Poole et al., 2022).

9.1. Limitations

The digital chessboard (4th tool) adopts a human-in-the-loop approach intended to capture ideas not accounted for and provide strategic input to further Delft3D-FM model interactions. However, while a number of what-ifs run through MAGE, there is an obligation to explain the uncertainty inherent in the approach that has been designed. Coastal management requires confidence in results, and quantifying these values is critically important through model calibration and validation and uncertainty explanations (Kroon

et al., 2025; Lyddon, 2020; Lyddon et al., 2023). MAGE's approach to addressing uncertainty is to provide transparency in its presentation section by explaining the limitations of scenarios. MAGE's lightweight coastal numerical model also requires further resources and further detailed uncertainty assessments. The proof-of-concept of MAGE numerical modelling was intended to be "lightweight," meaning that high-density models and calibration and validation phases require more rigorous development due to resource constraints. While MAGE has a twinned aspect from the variety of assembled data sources and the model aspect, its virtualisation and simulation require careful deployment and co-design integration in workshops to be effective instruments, guided by coastal engineers and scientists to qualify and support queries raised by the general public. Visualisation and the presentation of quantifiable information are key aspects that will require multiple iterations (Percival et al., 2020). Ultimately, reflecting on how MAGE, as a system, would function, it relies on careful curation and embedding as an artefact for engagement and decision-making.

Developing three tools for MAGE has achieved significant advances in the state-of-the-art through the transformer function that links numerical coastal models to game engine simulations, and a custom gameplay interface. MAGE, as a system, can be replicated across additional game zones (study areas) using computational resources and a game-engine pipeline, and will be released at the end of the project cycle as open science in 2027. However, long-term challenges exist around utilisation and the embedding of the tools within wider gamezones of significant areas of risk under NCERMS in the UK. In addition, MAGE, as a simulation artefact, can present sensitive visualisations of "what-ifs" to people whose properties may be affected by coastal erosion and flood risk during community consultation at scenario time points. Careful coastal adaptation pathway workshops are required to frame discussion about future preparation through co-design. Again, reflecting on the open questions in the introduction, MAGE, as a sandbox, has agency in expressing a number of future possibilities, educational learning, and experiences that are framed with stakeholders.

MAGE is limited as a learning system for pre-processing coastal scenarios compared to real-time computation, and there is a significant opportunity to explore surrogate AI models for synthetic coastal data. In addition, the replicability of MAGE as a proof of concept relies on expertise, access to HEC infrastructure, and the processing times of coastal model runs. Furthermore, existing investments in data sources and UK national data providers create a unique ecosystem that is not necessarily replicable in other countries. MAGE is a highly multidisciplinary team embedded within a wider Our Future Coast programme and work streams that hold particular team expertise and connectivity that would be difficult to apply in smaller research teams. In addition, MAGE, as a proof of concept, requires socio-technical collaboration and careful management of expert boundaries and scientific overlaps.

The extent to which risk is quantified in simulations is a current limitation; while this may be preferable for hazard and risk underwriting professionals and researchers, the rationale rests on two decisions. First, this quantified risk aspect has been limited in the current iteration. MAGE remains a black box due to deployment considerations in communities that could be affected by major changes across the two scenario phases. Second, further co-design of coastal adaptation workshops is required to embed the process and is limited from an ethical perspective. Our research acknowledges the large body of further work to be undertaken around hazard risk, uncertainty and visualisation. However, MAGE tools are open processes and replicable practices that can be adapted for purpose and deployment across other sites, or gamezones, such

as coastal cells in the UK (e.g., The Humber, Cell 1, Norfolk, Cell 3 or Cornwall, Cell 6 & 7) with higher sea-level and coastal erosion risks, or further afield.

10. Conclusion

MAGE is a proof-of-concept case study that has developed interrelated tools for SMP policies, coastal adaptation, and community education in the North-West. MAGE will develop and deliver additional game zones and community consultation events, wider dissemination activities, and further iterations of the 4th tool, particularly around the visualisation of risk and the coastal modelling of nature-based solutions alongside virtual and augmented variations of MAGE in the 5th tool. The MAGE contribution to knowledge is the translation of SMP policies into strategic serious games to enable participation, alongside the translation of numerical coastal models into a game engine and a unique interface. The MAGE sandbox and its portability enable deployment at workshop events with communities directly affected by a number of future simulations and scenarios, shifting the role of participation from one-way interaction to a co-designed, two-way experience, placing users at the heart of the decision-making space for coastal management.

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Conflict of Interests

The authors declare no conflicts of interests.

Data Availability

Three of the five MAGE tools are available here: mobile app for VGI and public coastal perceptions (<https://imagination.lancaster.ac.uk/project/lets-map-our-future-coast>), large-scale tabletop game of the North-West coast (<https://research.lancaster-university.uk/en/publications/mage-a-serious-game-for-coastal-futures>), MAGE mini game for KS3 Geography (<https://research.lancaster-university.uk/en/>)

publications/mage-mini-a-serious-game-for-coastal-futures). The remaining tools will be hosted in 2027: <https://futureenvironmentslab.co.uk>.

LLMs Disclosure

No LLMs have been used in the production of this research article.

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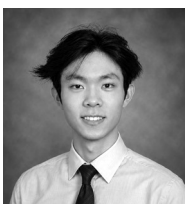
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