A DIGITAL GAME-BASED SIMULATION PLATFORM FOR INTEGRATED MARITIME SPATIAL PLANNING: DESIGN CHALLENGES AND TECHNICAL INNOVATIONS

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ABSTRACT

The 2014 EU Directive on Maritime Spatial Planning (MSP) lays down obligations for the EU Member States to establish a maritime planning process, resulting in a maritime spatial plan by 31 March 2021. The EU Directive defines key principles for planning such as evidence-based and stakeholder-oriented, for which integrative planning support systems (PPS) are needed. The MSP Challenge simulation platform has been designed for participative integrated assessment (PIA) and social learning. The authors present the design and engineering challenges as well as the innovative technical solutions of the platform: 1. A Unity-based game-server architecture; 2. incorporating a large volume and variety of geospatial, marine and maritime data; 3. interconnecting with the ecosystem modelling platform Ecopath with Ecosim (EwE); 4. interconnecting with simulators for shipping and energy, and; 5. providing technical functionalities to set up and moderate multi-player highly interactive game sessions. The authors discuss lessons learned and provide directions for future research and development for both the MSP Challenge simulation platform and maritime planning support systems at large.

KEYWORDS

Ecopath with Ecosim (EwE); Geo Information Systems (GIS); Marine Ecology; Maritime Spatial Planning (MSP); Participative Integrated Assessment (PIA); Planning Support Systems (PSS) Serious Game; Shipping; Simulation; Offshore Wind Energy.

INTRODUCTION

Human activities at sea such as offshore wind production, shipping and fishing, easily get into each other's way. They also have a long-term impact on the marine environment. In 2014, the EU parliament and member states therefore agreed on the Directive (2014/89/EU) on Marine Spatial Planning [*Directive 2014/89/EU of the European Parliament and of the Council of 23 July 2014 establishing a framework for maritime spatial planning* 2014]. This directive lays down obligations for the EU member states to establish by 31 March 2021 a maritime spatial planning process and resulting maritime spatial plans with a minimum review period of 10 years. MSP is defined as a process by which the relevant member state's authorities analyze and organize human activities in marine areas to achieve ecological, economic and social objectives. The EU Directive on MSP gives five guiding principles for the planning process:

- Integrated planning of all spatial uses and possible conflicts.
- Evidence-based i.e., guided by best available knowledge and data.
- Ecosystem-based e.g., taking into account the monitoring of the cumulative impact of human activities on the ecology.
- Transboundary consultation and co-ordination at sea basin level.
- Information of the general public and consultation of all relevant stakeholders.

In this article, we present the insights and innovations achieved in the design and engineering of an innovative Planning Support System (PPS) to support the objectives and principles of the EU Directive on MSP.

PROBLEM FORMULATION

Abiding by the above principles in the EU Directive on MSP is easier said than done. Mainly because the principles are inherently dilemmatic. Evidence-based planning builds upon a large volume and variety of data and other forms of information, about geo-physical and bio-natural systems and maritime sectors, such as shipping, fishing and renewable energy. However, such data and knowledge is compartmentalized in sectors and disciplines. Getting access to proper data is only the first challenge. Integrating a large volume and variety of data from different sectors that come in different formats is another challenge. Several initiatives have been taken to harmonize data, as well as facilitate data and information exchange, at national or sea basin levels [Emodnet 2019; Helcom 2019]. However, the centralized availability of a large volume and variety of harmonized data does not automatically lead to a better understanding of MSP. We simply do not know very well how maritime activities deployed by different economic sectors interact with each other, or with the marine environment. Just to illustrate, wind farms can lead to a re-routing of shipping lanes which may cause an increase of fuel consumption. This causes an increase in Co2 and other emissions and relocates pressures, such as noise, which effects the marine environment. In reality, numerous other factors also from other sectors come into play. They all interact in a complex, non-linear manner, with self-reinforcing and self-mitigating feedback loops and significant time delays between cause and effect [Levin et al. 2013]. Furthermore, planner-stakeholder interactions themselves are a form of complex socio-political system behaviour [Kannen 2012]. Sectoral and transboundary consultations often lead to political compromises that from an evidence-based and integrated system perspective are less rational or sometimes even very irrational. In sum, the combined principles of the directive would require planners and stakeholders to develop a proper understanding of the complexity of MSP, particularly the cross-sectoral interactions over a longer period of time and their cumulative effect on the marine environment. However, planners and stakeholders are often specialists driven by their own interests and beliefs. They are not always trained in the use and interpretation of data and support systems, or in dealing with the uncertainties of and limitations in scientific knowledge. Therefore innovative planning support methods are needed.

THEORY AND CONCEPTS

Social learning

Planning is often seen as a technical practice. A matter of assigning space to different economic and ecological functions, by optimizing costs, benefits and constraints. However, planning is also social learning [Friedmann 1981; Muro and Jeffrey 2008]. A process in which politicians, planners, experts and stakeholders exchange knowledge, values and ideas. Where they can come to a shared and higher level of understanding about the object of planning (such as wind farms, shipping and fishing at the North Sea) and each other. High quality social interaction is a prerequisite for social learning, not a guarantee. Therefore, planning as social learning heavily relies on methods and approaches that can bring stakeholders to the table and can facilitate their interaction. It also relies on methods that can bring best available data and knowledge to the stakeholder's table and their discussions. Engaging and committing stakeholders to a planning process by itself can be a real challenge. Planning methods should therefore also be able to motivate stakeholders. This can be done by making it 'engaging' as well as safe, transparent, efficient and fair.

Participatory integrated assessment

Participatory Integrated Assessment (PIA) has been proposed as a step towards planning as social learning. It is defined as 'a structured process conducted with stakeholders to assess the environmental, economic and social dimensions of a complex issue and the impacts of policy choices. It contributes to social learning – a convergence in the stakeholders' perspectives on the problem and its solutions – which creates a basis for more sustainable, collective action' [de Kraker et al. 2011]. For the reasons above, MSP is in dire need of innovative approaches and tools for PIA so that planners and stakeholders can jointly assess the current status and explore the future consequences of planning decisions [Jean et al. 2018].

Planning support systems

In the last few years, several Planning Support Systems (PSS) for ecosystem-based MSP have been developed, each one having specific strengths and limitations [Depellegrin et al. 2017; Gimpel et al. 2018; Menegon et al. 2018; Pınarbaşı et al. 2017, 2019; Stelzenmüller et al. 2013]. Few of these tools can be qualified as 'integrated' in the sense that they link a great amount and variety of data with simulation models for a wider range of maritime sectors, such as energy (offshore wind production, energy grid development) or shipping. Furthermore, most PSS tend to be specialized and scientific, making them useful for desk analysis but less effective in an interactive context, so as for stakeholder engagement, transboundary consultation, scenario development or co-design processes.

Simulation/serious games

In search for methods and tools that can support 'planning as social learning' by PIA, simulation games or serious games (SG) have come to the forefront [Mayer 2016]. Games are good at simulating complexity on the basis of a large volume and variety of data. They can engage and scaffold the user-players in learning from the game-system and other players. Through game-play, planners and stakeholders experientially understand the dynamic interrelations among various subsystems, the interdependencies among the actors and the consequences of actions well into the future [Duke 1974]. The MSP Challenge simulation platform was developed to support planning as social learning, by trying to overcome some of the dilemmas in the EU directive with game thinking and game technology. In the remainder of the article, we focus on the technical design and engineering of the platform.

MATERIALS AND METHODS

Objective

The main objective of the research is to contribute to the understanding and innovation of planning support systems for social learning through the use of game technology and game principles. The object of research is an integrative simulation platform for participatory integrated assessment (PIA) to support the EU Directive on MSP, in its objectives and principles.

Research approach

This research objective can be achieved in different ways. The performance of a platform for planning support needs to be confirmed in field studies on the basis of proper evaluation data, which demonstrates the performance of the system on the basis of pre-defined criteria. These criteria can be the technical performance of the platform (e.g., the robustness of its functionalities), its use and usability, the internal and external validity of the data, models and simulations, and finally the observed social learning of the user-players as well as how this contributes to a better marine planning process and outcome. However, where this has partly been done in previous studies and is subject to pending studies, we limit ourselves in this article to a presentation of the design and engineering of the artefact itself, i.e., the simulation platform [Abspoel et al. 2019; Groot et al. 2019; Hutchinson et al. 2018; Jean et al. 2018; Keijser et al. 2018; Mayer et al. 2013; Steenbeek et al. 2020]. We focus on the requirements, design and technical challenges, and innovations achieved. The game architectural results are relevant because they can inspire and guide the development of maritime and terrestrial planning support tools at large.

Research questions

1. Requirement analysis: what are the requirements of an interactive simulation platform that can support MSP as social learning?
2. Design and engineering challenges: What are the technical challenges and breakthroughs that need to be realized?

3. Solutions and innovations: What solutions and innovations have been achieved and what are the lessons learned?

The MSP Challenge simulation platform in a nutshell

The MSP Challenge simulation platform [“MSP Challenge website” 2019] has been designed to help decision-makers, stakeholders and students understand and manage the maritime (blue) economy and marine environment [Abspoel et al. 2019; Mayer et al. 2013]. The MSP Challenge simulation platform integrates *real* geo-data (both marine and human activities) sourced from mostly open data portals, notably HELCOM [Helcom 2019], EMODnet [Emodnet 2019], Copernicus [Copernicus 2020] and national data centers. It subsequently connects these data to science-based simulation models for shipping, energy and ecology (Ecopath with Ecosim [Ecopath International 2019]). Finally, a game engine [Unity 2019] forms the foundation of the frontend end-user application, thus bringing all of the aforementioned together. This simulation platform allows anyone – experts as well as non-experts - to creatively operate it for scenario development, and/or for multi-player game sessions. This can have multiple purposes such as scenario exploration, co-design, validation or policy-oriented learning. Although the simulation platform has taken a significant step towards becoming a next generation marine planning support system, it continues to use play mechanics, in the form of player roles, scenarios and challenges. It furthermore links to a knowledge repository and a Virtual Reality (VR) module so that the player-planner can actually click for more information in the game, and have a virtual representation of consequences or future innovations. In 2015, the simulation platform became part of three EU funded projects: NorthSEE (2016-2019) [NorthSEE n.d.], BalticLINes (2015-18) [Baltic LINes n.d.] and SIMCelt (2015-17) [SimCelt n.d.]. The MSP Challenge simulation platform now hosts a bespoke edition created for the Clyde Marine Region in Scotland and the complete Baltic and North Sea basins. At the time of writing, within a year of its launch, the three editions have been used by hundreds of stakeholders, planners and students [Abspoel et al. 2019].

RESULTS

Requirements

On the basis of the principles of the EU Directive on MSP, we defined the following requirements for the platform.

1. Integrated: Best available representation of natural, geo, ecological and physical systems, economic sectors and human activities. Dynamic and complex interactions between sectors and ecology. Simulation of socio-technical complexity, for instance through cumulative and emergent effects, well into the future. Analysis of conflicts between sector activities, as well as possible synergies (combined use).
2. Evidence-based: Integration of a large volume, variety of geospatial, maritime and marine data, of different formats and types. Integration of this data into one data server for simulation and user interaction. Representation of non-confirmed data and information such as initial plans, sketches and search areas. Representation of qualitative information (text, pictures) such as on marine species or wind farms.
3. Eco-system based: Communicates with one or more science-based ecology models for different eco-systems. Should be able to assess the impacts of planning decisions on marine ecology, over time.
4. Transboundary: Represents simultaneous MSP by multiple countries in a sea region. Supports international consultation and collaboration. Shows the consequences of national decisions at sea basin level.
5. Stakeholder consultation: Able to incorporate the beliefs systems of planners and stakeholders. Can simulate the social-political interactions among planners and stakeholders. Should be engaging, motivating and easy to use. Flexibility and adaptability of use at different levels of expertise, involvement, for different purposes and regions.

Design and engineering challenges

These requirements gave the following design and engineering challenges.

Game architecture

The first and main technical challenge was to design and build a very flexible and multi-purposed system architecture that in principle would be able to host a minimum of three sea regions, i.e., the North Sea, Baltic Sea and Clyde River Estuary (near Glasgow, Scotland). These sea regions are significantly different in terms of geographical scale and size, political institutions, economy and ecology. The innovation was achieved by developing a modular system architecture with a Unity game engine end-user frontend application (discussed below).

Data server and data communication

The second challenge was to build a data server architecture that can handle a large volume and variety of real GIS data, obtained from many different sources in different formats, vector and raster. This includes geospatial data (e.g. shorelines, bathymetry, rivers), geo-political data (e.g. territorial waters, exclusive economic zones), facilities data (e.g., ports, harbors, cities), human activities data (e.g. ship traffic, energy infrastructures, fishing), ecology protection data (e.g. marine protected areas, fishery closures) and ecology data (e.g. biomass, biodiversity indicators). A great deal of this GIS data is publicly available, but other types of information and secured data obtained from specific authorities also needed to be included. The data server needed to be able to import all kinds of GIS data. Simulation-gaming requires a very high consistency of underlying data, or otherwise it will significantly disrupt game performance and game-play. Despite EU harmonization and standardization efforts, much of the marine and sectoral data is highly distributed, generic and very inconsistent. Often there is too much or too little detail in the data for planning or different types of errors. Real-time use of distributed data within the simulation platform was therefore not a realistic option. The data for the simulation platform needed to be verified and cleaned. Meta-data status would need to included, and it should be easy for anyone to add, change or disable data layers.

Link with existing ecology models

The third challenge was to develop interfaces between the MSP Challenge simulation platform and one or more, external modelling and simulation platforms for marine ecology. The technical team opted for Ecopath-with-Ecosim (EwE), one of the most widely used platforms for ecosystem modeling [Ecopath International 2019]. The main benefit of EwE is that it has an active user and developer community that has been developing models for marine ecosystems across the globe for several decades. These models are subjected to scientific validation studies and peer scrutiny. Furthermore, EwE has various useful subcomponents for modelling (Ecopath), simulation (Ecosim) and spatial distribution (Ecospace). Working with the EwE community, we created an MSP Challenge with Ecopath Link (MEL) that allows any EwE model to communicate with the MSP Challenge simulation platform. MEL is also an example for future linkages with other (ecosystem) models.

Embedded dynamic simulations

The fourth challenge was to simulate the interactions in and between different sectors, and ecology. Unlike for marine ecology, limited external and flexible simulators for significant economic sectors such as shipping or energy exist. However, there are massive amounts of data. Data about ship movements are generated through the Automatic Identification System (AIS) installed on ships. This data is used to generate heat maps on for instance traffic intensity, congestion, risks etc. However, this is either historic or real-time data. The data cannot by itself evaluate the consequences of planning decisions for the future, such as how shipping routes will change due to the construction of wind farms. Mutates mutandis, static data about wind farms do not say anything about how much energy will be produced in the future, taking into account decision factors such as location, distance to shore, wind speed, type of wind turbines, cables and the possible co-sharing of wind farms or energy grids among countries. The technical team was therefore challenged to develop two simulations - for shipping (SEL) and for energy (CEL) - and embed them into the platform. Furthermore, the team needed to develop environmental pressure models for shipping (e.g., noise), energy structures (e.g., hard substrate) and other human activities in order to assess the impact of future developments on the marine environment. In other words, MEL (ecology), SEL (shipping) and CEL (energy) needed to interact.

Player-user interaction

The fifth challenge was to use game technology and game thinking to create a highly engaging and useable platform, for all kinds of users and use purposes independent of age, level of expertise, familiarity with GIS or location in the world. The platform should allow participants to collaborate as well as experience conflicts among countries and sectors. Thus it needed to cater to game mechanics such as challenges (setting country objectives in the platform), scenarios (narratives), construction and design (sketch, implement or delete a plan), social interaction (multi-player, simultaneous), and feedback (dynamic key performance indicators or KPIs). The design and engineering of the platform was approached as an online multi-player strategy game. Most challenging was the fact that the platform needed to create a shared world that would change as a results of many disjointed decisions over time. As in reality, players for some reasons will implement plans that are impossible or unlikely. Think of wind farms in areas deeper than 30 meters, or in the middle of a shipping route blocking the entrance to a major port. Players will make decisions that are contradictory or inconsistent with earlier decisions or those of other players. The simulation platform would need to allow errors and inconsistencies without crashing. It would have to give feedback so that players can correct and improve without slowing down game-time. Artificial Intelligence (AI) could help but should not be allowed to take over. As in an online strategy game, the simulation platform would need to show the future consequences of ‘bad’ decisions.

Game manager

The sixth challenge was to make sure that the platform could be used in any location in the world, under different conditions and in different play modes. This included playing online on a central server, installing a dedicated server clone or setting up a temporary local server on a laptop in remote locations without proper internet access. Game managers would need to be able to set up and moderate a session, e.g., to define its objectives, duration and player groups. One of the main design and engineering challenges concerns the configuration of different interconnected time dimensions. First, the play time or session duration needs to be configurable, which can be a few hours to several days (continuous) or weeks (discontinuous). Second, the planning period needs to be configurable, representing the simulated time needed to complete an MSP process. This is typically two or three years. Third, the plan era needs to be configurable, representing the horizon of the marine spatial plan, usually somewhere between four to ten years. In this fashion, a group of players can take two days (play time) to simulate two planning periods (2018-2020; 2026-2028) with a simulation of its effects over two plan eras (2018-2026; and 2026-2032).

SOLUTIONS AND INNOVATIONS

In this section we describe the main solutions and innovations to meet the challenges above.

Innovation 1: Game architecture

Figure 1 gives a complete overview of the game architecture of the MSP Challenge simulation platform. The server consists of three main parts: the MSP Challenge server side (left), hosting server side (middle) and client side (right). Functional subsystems in the three parts are numbered as C1-9 for further discussion below.

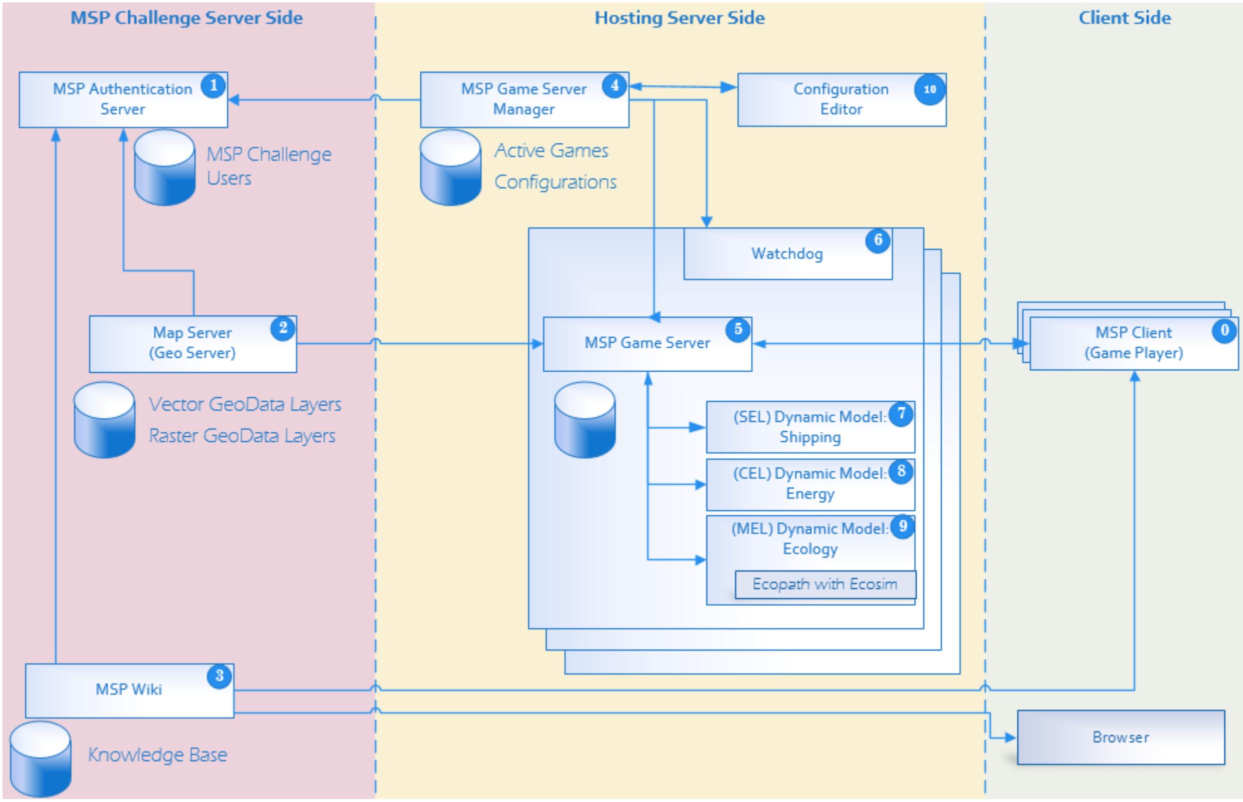

Figure 1. MSP Challenge simulation platform architecture diagram

MSP Challenge server side

The MSP Challenge server side consists of three main components: an authentication server (C1), a map server (C2), and an MSP wiki (C3). These server components take care of the underlying functions such as user and session authentication and the connection to a data server. This is needed to host, moderate and play an MSP Challenge game session.

- Authentication server (C1) - The MSP authentication server is a user management system based on UserSpice [UserSpice (website) n.d.]. It registers and stores all information about users and their permissions. It communicates it to the different components in the platform, mainly the MSP map server (C2), the MSP wiki (C3) and the MSP game server manager (C4).

- Map server (C2) - The MSP map server is an installation of GeoServer which implements industry-standard map-based protocols [GeoServer n.d.]. The MSP map server is a repository of map layer information optimized for the simulation platform. Although it is not directly linked with any session, it provides source data for all three regional editions or future editions. When a new MSP game server (C5) instance is created, it obtains its data from the MSP map server (C2). This can then be used by participants and dynamic models during a session. Furthermore, it provides the assurance that if a geo-data layer is updated in the map server (C2), future instances of the MSP game server (C5) will have that information seamlessly updated.
- MSP Wiki (C3) - The MSP wiki is an installation of MediaWiki [MediaWiki n.d.]. Besides information and tutorials about the MSP Challenge simulation platform itself, it has textual and visual information about human activities and marine life. During a session players/users can access the MSP Challenge wiki directly from the client. If they have an account with the MSP authentication server (C1), session facilitators or players-users can make edits to the wiki before, during or after a session. Users who wish to host their own game servers (explained below) can also set up their own dedicated institutional MSP wiki.

Figure 2. Screenshot of a page on the MSP Wiki (C3).

Hosting server side

The hosting server allows institutions to host MSP Challenge game sessions on a central or local server. It comes with instructions and installation packages on a MSP Challenge user community wiki [MSP Challenge n.d.].

<u>MSP Game Server Manager (C4)</u> - The server manager is a simple but vital piece in the hosting process. It serves two main purposes. First it retains a list of world configurations, a blueprint for creating instances of sessions. It lists simple things such as the region name, colour schemes, but also more complex behaviours, such as the simulation parameters and what data layers are active and modifiable. Second, it spawns the MSP game server (C5) instances based on specific configurations. It keeps track of simple monitoring and control data of the state of dependent MSP game servers. MSP Challenge hosts can easily create a new MSP Challenge session. They log into the MSP game server manager (C4), select a configuration and press a start button. They can stop existing sessions, backup results, and delete

sessions. The hosting server can also be installed on a single PC on a Local Area Network (LAN) to assure a stable connection.

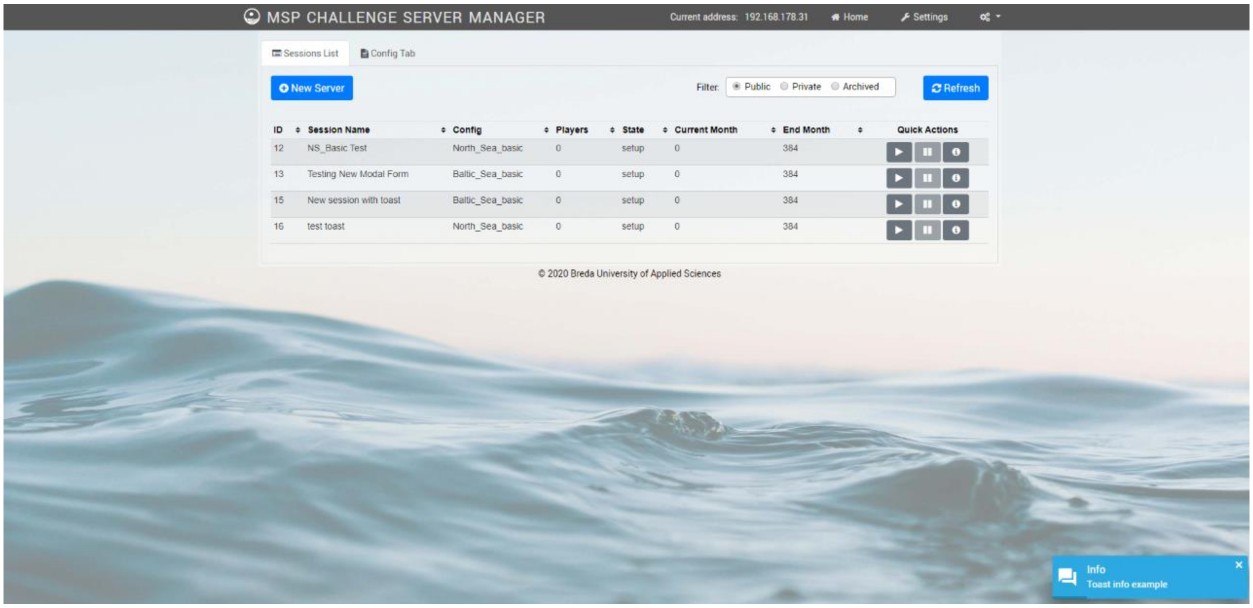

Figure 3. Screenshot of the MSP Game Server Manager (C4)

<u>Configuration Editor (C10)</u> - Configurations are blueprints for instantiating sessions. A configuration file is a single complex .json file that can be edited by a text editor. However, this requires technical knowledge and expertise. We therefore created a support MSP configuration editor (C10) which makes it easier for simulation platform hosts to edit, customize or add to the standard configurations. This may entail changing the data or adding/removing data layers, changing country planning objectives (e.g., develop X square nautical miles of marine protected areas by 2030) or adding future planning options (e.g., building a floating wind turbine in deeper waters).

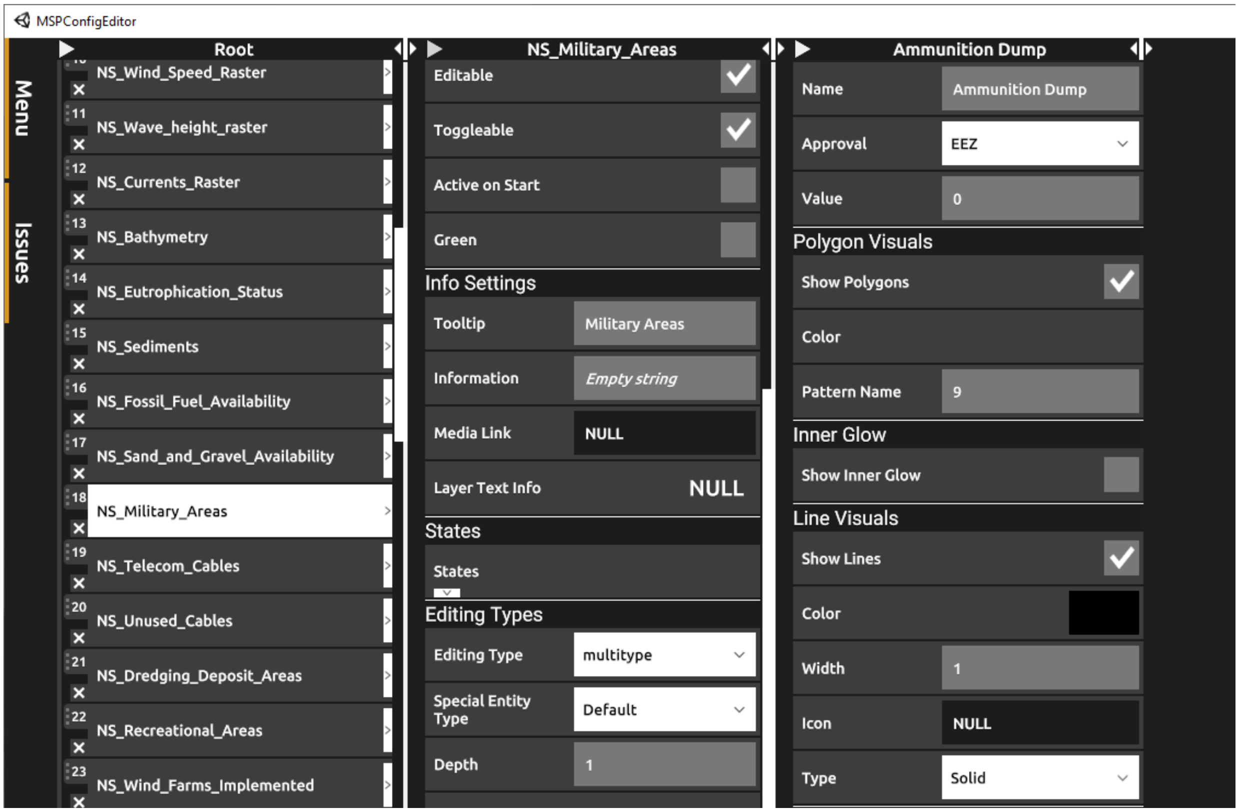

Figure 4. Screenshot of the Configuration Editor (C10).

- Game Server (C5) – The game server is a web application with a database that stores and maintains the world state available to all connected MSP Clients (C0) and dynamic models (C7, C8 and C9). The MSP game server (C5) is instantiated by C4, with a unique session identifier and a configuration. After the session identifier is registered, it will give a unique URL to the game server manager (C4). With this URL, the game server (C5) exposes a RESTFul API by which an external component can retrieve and modify the world state. The game server (C5) has no knowledge which systems are connected. It only propagates changes to the world state and it is the responsibility of the connected components to behave and perform the correct modifications to the world state. In this fashion, it becomes possible to create cascading effects (effects that trickle down from multiple systems) and remove or add new dynamic models without major rework.

- Watchdog (C6) - The MSP watchdog is an executable that launches and controls the dynamic models in use (typically the ecology, shipping and energy simulations) for a specific MSP session. It keeps an eye on existing dynamic models. If one fails, it logs the information of the failed system and re-launches it so that the service can pick up again. This gives stability to the whole system. In addition, the watchdog can distribute computational power across multiple machines to improve the speed and stability of the simulations.

Client side

MSP Challenge Client (C0) - The MSP challenge client is probably the most sophisticated piece of design and engineering in the simulation platform. The client was built in a Unity game engine [Unity 2019] and links via a RESTFul API to the game server (C5). The MSP Challenge client is the end-user’s main conduit to the entire platform. Changes to the world by the players are sent to the game server which then replicates to the other clients connected to the same server. The client takes care of rendering visual information and supports all user interactions. This includes, viewing the sea basin world in its current and future state. Players can sketch, implement or archive plans. The results are calculated by the simulators but displayed in the client through performance graphs, such as increases or decreases of biomass, shipping route efficiencies, or energy production.

Innovation 2: MSP Challenge EwE Link, MEL (C9)

The technical team designed and created an interface application named MEL between the MSP Challenge simulation platform and EwE [Goncalves et al. 2019; Steenbeek et al. 2020]. MEL converts player actions in the game into pressure maps that can be read by the components of EwE to calculate the ecological effects. This is done through a activity-pressure conversion table. This table assigns pressures (see below) to all human activities, such as wind farm construction, fishing or shipping.

1. Noise - The spatial distribution and intensity of low-frequency noise resulting from shipping, construction. The noise map layer acts as an environmental driver layer in Ecospace and affects per-cell foraging suitability for functional groups sensitive to low-frequency noise.
2. Surface disturbance - the spatial distribution and intensity of physical disturbance at the surface, which includes pollution, presence of temporary and transient structures and vehicles, turbidity due to anthropogenic activity, etc. The surface disturbance map layer acts as an environmental driver layer in Ecospace and affects per-cell foraging suitability for functional groups sensitive to disturbances at the surface.
3. Bottom disturbance - the spatial distribution and intensity of physical disturbance at the sea bed level, which includes pollution, presence of temporary structures, turbidity and reduction of visibility due to anthropogenic activity, etc. The bottom disturbance map layer acts as an environmental driver layer in Ecospace and affects per-cell foraging suitability for functional groups sensitive to disturbances at the bottom.
4. Artificial substrate - the spatial distribution and intensity of artificial structures that provide shelter and/or habitat to sensitive functional groups. This layer acts as an additional habitat in Ecospace to increase habitat-derived cell suitability in Ecospace.
5. Protection - the spatial distribution of locations where fishing is impossible due to the presence of other activities, or prohibited through fisheries restrictions. This per-fleet map layer acts as an Marine Protected Area (MPA) layer in Ecospace, blocking fishing effort for all sensitive fishing gears in cells where MSP activities that generate this pressure are present;
6. Fishing intensity - a scalar pressure to increase or decrease the nominal amount of fishing across the game area.

Human activities take place at a certain location (or cell) in the sea basin grid at a certain moment in time. Planning of human activities changes the cell states. Ecopath defines the food web for a sea basin (type, number and interaction between marine species). Ecospace reads the spatial dimension of the pressures.

Ecosim calculates the effect of it, for instance certain species moving away from pressures. This leads to four types of Ecospace predictions: 1. group biomass; 2. group catch; 3. fleet effort; and 4. biodiversity indicators. The aggregated outcome in time and space is pushed back to the simulation platform. It reads the data and portrays it as KPIs, visualized in heat maps and graphs. This generic way of working of MEL makes it possible that any EwE model, existing or to be developed, can be linked to existing or new editions of the simulation platform. At present, EwE models for the Baltic proper, the Bothnian Gulf, the entire North Sea and the Clyde Marine region are linked to the respective editions. First studies to assess the internal and external validity of the model behaviour, as well as use-ability in game sessions show positive results, but their discussion is out of scope here [Goncalves et al. 2019; Steenbeek et al. 2020].

Innovation 3: Dynamic Models SEL (C7), CEL (C8)

The team designed and built two dynamic models, or simulators, to calculate the effects of planning decisions on shipping (SEL) and energy (CEL). Much like MEL, they drive the game-play. They turn static data layers into dynamic scenarios to give data and visual feedback to the players.

1. Shipping (SEL, C7) – While preferred or mandatory navigation routes tend to be very constant for obvious reasons, wind farms are significantly interfering. With few exceptions, shipping is not allowed in wind farms, and safety distances apply. Smaller ships will freely navigate their way around them. For larger ships (IMO) routes and traffic separation schemes would need to be re-established. SEL combines historic and static data about ship movements and navigation with planning decisions to calculate on a monthly basis the new navigation. It does so for different types of ships, cargo, tanker, maintenance, passenger and ferry ships. Baseline parameters such as port metadata and ship movements between specific ports can be updated before a game session. The main parameters of the simulation are:
   - Shipping lanes **-** route segments in a sea basin. Designated shipping lanes are usually stretches for specific types of ships.

- Ports and gates – starting and end points of ship movements. Defined as point geometry on the basis of metadata, such as fueling types, port facilities and the number of incoming or outgoing ships.
- Restriction areas – block all or certain types of ships from passing through. No-shipping areas, aquaculture and wind farms are examples of restriction areas.

SEL calculates and gives feedback in the form of these KPIs:

a. Route efficiency – the average efficiency of a particular port's routes to all of its destination ports in the simulated month, calculated as the actual navigation distance as compared to the rectilinear navigation distance. A straight line between this port and all of its destination ports gives a route efficiency of 100%.
b. Port intensity - the number of ships a port produced in the simulated month. This value is the actual number of ships that are sent from the particular port to a destination, and provides an insight into port development.
c. Lane intensity - the number of ships travelled over each shipping lane. If the shipping route that is actually taken comprises of planned shipping lanes, then the number of ships traveled over those lanes are added to their metadata to provide insights into how well-traveled the lane is.

First studies to assess the internal and external validity of the model behaviour, as well as usability in game sessions show positive results, but their discussion is out of scope here [Groot et al. 2019].

2. Energy (CEL, C8) – The energy simulation model CEL in the platform calculates how much offshore wind energy is being generated, transported and shared among the countries. Finance and economy of offshore wind farm development, production and consumption are outside the scope of MSP and this simulation platform. The simulation model works through 'grids' that consist of power sources

(turbines in a wind farm), cables to connect wind farms to shore, transformer stations to connect cables at sea or land and sockets as the entry point on land. In MSP Challenge players can plan an entire offshore energy system, based on multiple independent grids. They can co-share the energy infrastructure, energy production and consumption. Generated electricity may fluctuate and differ markedly from maximum or estimated production. This can be due to mismatches between energy production (maximum gigawatt) and capacity of the grid, transformers or sockets.

CEL calculates and gives feedback in the form of these KPIs::

a. How much energy (in MW or GW) has been produced or transmitted over the different elements in a grid: wind farms or other sources, cables, transformers, sockets.
b. How much energy each of the connected countries has received from a particular (shared) grid.
c. How much energy in total each country team has produced, consumed and shared through all grids.

First studies to assess the internal and external validity of the model behaviour, as well as usability in game sessions show positive results, but their discussion is out of scope here [Hutchinson et al. 2018]

Innovation 4: User interaction

User interactions were carefully designed with game mechanics in mind. Innovative solutions were found to balance realism (the data, simulators), the social learning (scaffolding) as well as the engagement factors (immersion, engagement) [Harteveld 2011]. We present the main mechanics built into the game features and functionalities:

1. <u>Narrative:</u> In the platform, countries are identified not by their real names, but through their colour coding: country yellow (Germany), orange (the Netherlands) etc. There is limited background

information about the country, such as politics, economy, because this changes constantly and should be brought into the game by the player-users.

2. Challenges: The game manager and users can define qualitative and quantitative country objectives in the system. At the end of the game, the players-users can evaluate to what extent they achieved them, or changed them midway.
3. Construction: Sketching and drawing plans in the platform is easy and fun to do.
4. Visual attractiveness: the simulation platform does not have the clean appearance of a typical GIS system. It is visually appealing.
5. Feedback: Players can monitor their performance on a dashboard consisting of data and graphs, and through dynamic heat maps.
6. Mediated interaction: the platform has a text communication function and a system for consultation and approval of plans.
7. Role-playing: the flexibility of the platform allows session moderators to add role-play if and when they wish, for instance through events, setting up discussion tables where stakeholders bring their digital plans to the table, reporting to a role-played minister, or appealing to a court.

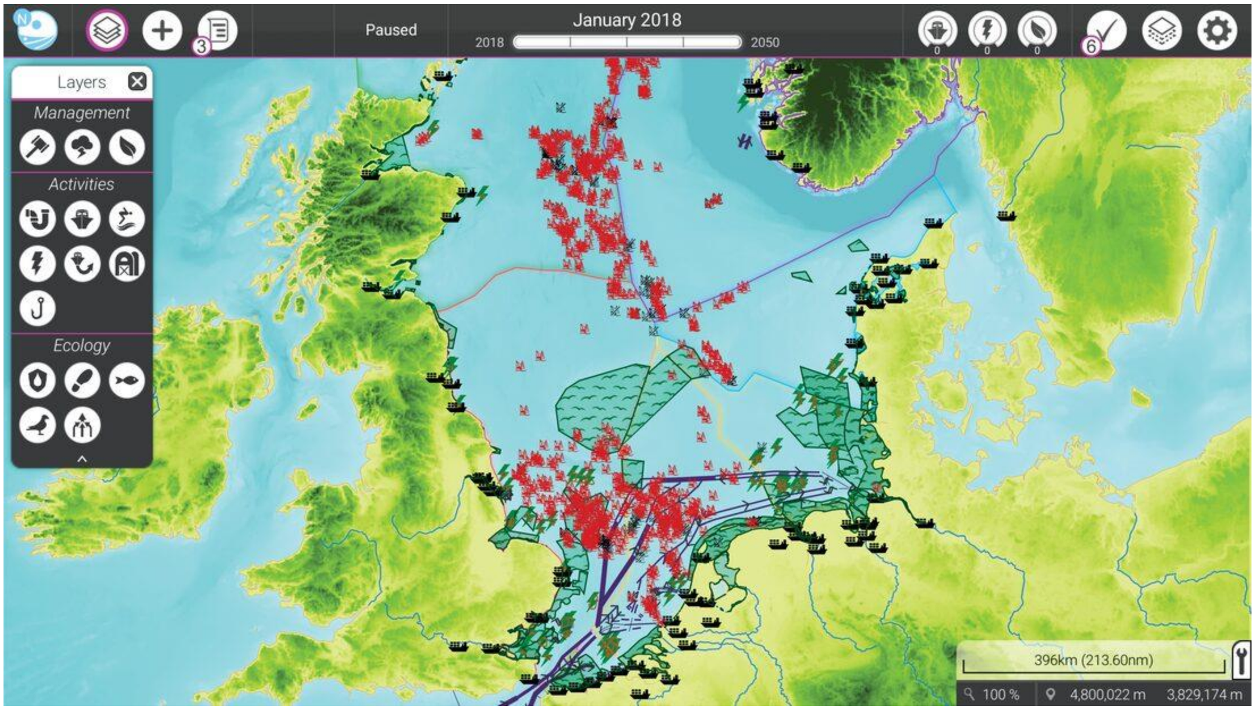

Figure 5. Screenshot of the MSP Challenge Client (C0).

Innovation 5: Game session management

The MSP Challenge Client also includes several game session management functions, i.e., functions to create, manage and moderate a session. These are as follows:

1. Dividing an MSP era into a number of years for player-user planning and a number of years for simulation only.
2. Pushing forward the simulation time to simulate consequences of earlier planning.
3. Controlling time: starting, pausing, slowing down or speeding up simulated time.
4. Playing in 'God mode', so as to make decisions for anyone or all of the country areas. This also enables problem solving, for instance by pushing forward plans that players forgot to implement, or fixing certain errors in a plan (e.g. when players-users forgot to connect a wind farm to a grid).

CONCLUSION

With the objective of developing a planning support system based on social learning and serious/simulation game design and thinking, we have presented the requirements, nature and components of the MSP Challenge simulation platform. We also discussed the technical challenges we faced, as well as five particular innovations we developed.

A discussion of the results and findings from the game sessions concerning player-user behaviour, model responses, or the nature and future of MSP itself, are out of scope here. They are, however, subject to very interesting and relevant future research. After all, with this platform and its widespread application we can witness the dynamics and outcomes of social learning and MSP itself. The many sessions we have already hosted with the platform inspire hypotheses concerning how MSP will develop in terms of process and outcomes. These are subject of future studies and publications.

The development of the MSP Challenge simulation platform from 2016 onwards took place in close collaboration with many authorities, stakeholder representatives, knowledge institutes in the aforementioned sea regions, and beyond. The experts and stakeholders provided the data and the conceptual understanding. However, the design and engineering team needed to turn it into a consistent world that could simulate complexity. The team worked in iterations, where design, test sessions, pilots and stakeholder sessions alternated each other in a rapid pace. All in all, the design and engineering process itself brought experts and stakeholders together to give a completely new understanding of social learning, namely by game design and game-play. It also brought game technology and game thinking to different parties in Europe and beyond: data portals, government authorities, knowledge institutes and scientific communities such as those around EwE.

We foresee that planning support systems can innovate further with game technologies such as Virtual and Augmented Reality. Imagine visiting a future floating offshore wind farm in VR. AI would allow to model the responses of certain types of stakeholders, as done in many entertainment games. AI could also help to find innovative and creative solutions for spatial conflicts between sector interest and value systems.

Most importantly, the architecture of the simulation platform is future proof. It is ready to host editions for other sea regions. It can connect to other simulation models, and incorporate more and better data sets. Given the EU-MSP Directive, other EU sea regions can benefit from the technical innovations achieved, e.g. the Mediterranean or Black Sea, the Gulf of Biscay and wider EU areas in the Atlantic Ocean. The uptake of the MSP Challenge simulation platform is promoted in the worldwide MSP community through our online user community. Our vision is that the MSP Challenge simulation platform will become a standard in integrative marine planning support, either because it will be carried forward by others or because it will inspire the development of other, even better planning support systems.

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