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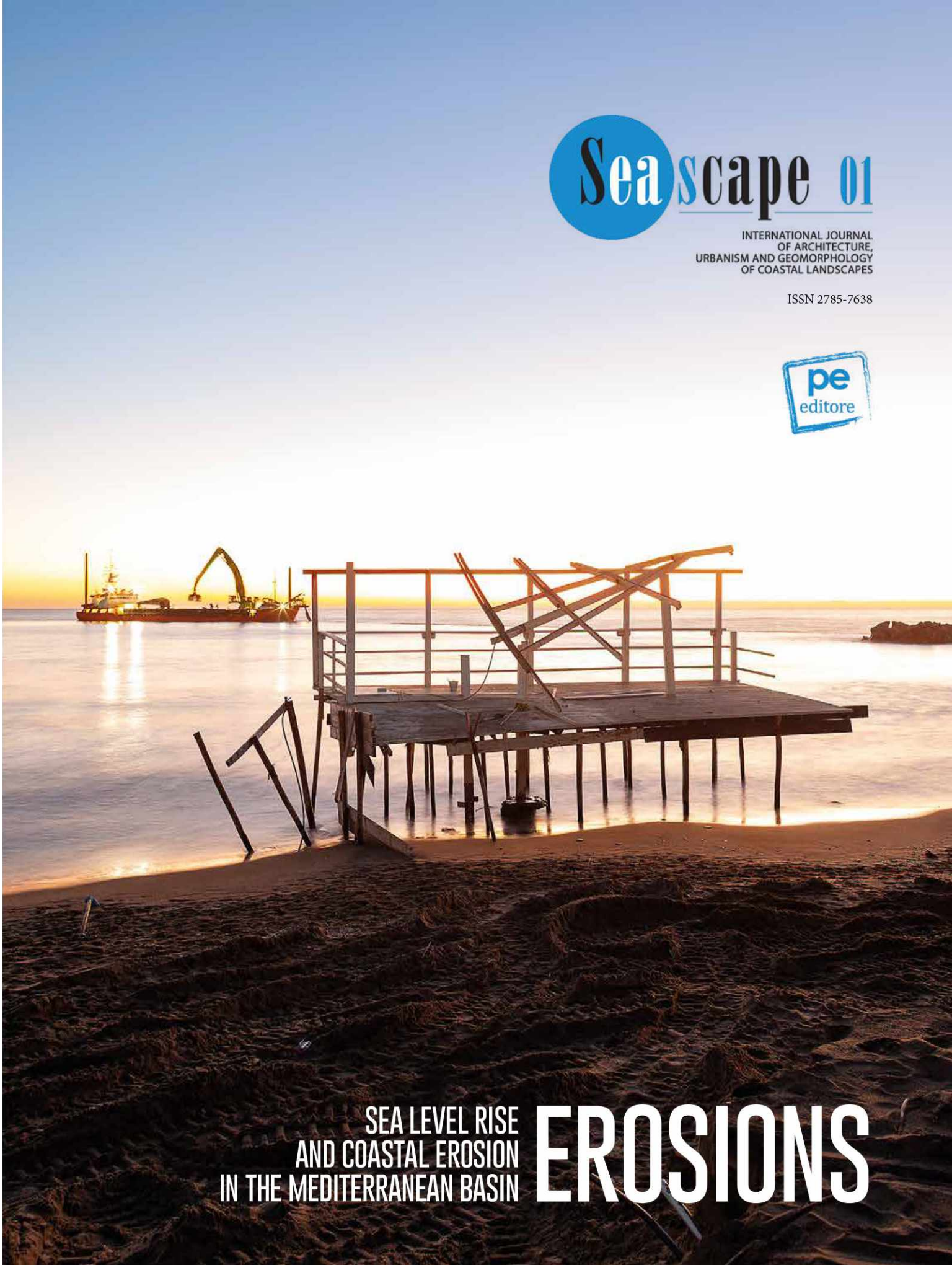

SEA LEVEL RISE AND COASTAL EROSION IN THE MEDITERRANEAN BASIN

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EROSIONS

SEA LEVEL RISE AND COASTAL EROSION IN THE MEDITERRANEAN BASIN

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Fig. 00_ The "Parco del Mare". Picture shot from South to North of the 1st stretch completed, southward of Rimini harbour. Photo by the Municipality of Rimini 2021

INTRODUCTION

Absolute Sea Level Rise and land subsidence threaten coastal plains all over the world, exposing developed areas to more frequent and severe flooding (Hinkel *et al.* 2013). Any adaptation strategies will produce significant changes in the coastal landscape, with relevant impact on residents' life, both from the social and economic point of view. Stakeholders' involvement is therefore a key issue, and their expectations will drive decision makers and influence adaptation costs.

A study performed for the World Bank (Nicholls *et al.* 2019) estimated that, in the worst RPC scenario, 32% of the world's coast will be defended over the 21th century, with a cost of US$18.3 trillion; whereas along the remaining 68% managed retreat or nature-based solutions are estimated to have better cost-benefit ratios. If a defence strategy is adopted today, there must be certainty that there will be resources in the future to maintain it, since the largest part of this money will be used to maintain old structures and those that will be made in the next decades. Otherwise, citizens are given a false security.

Managed retreat is generally considered the best adaptation strategy when future generations are considered, and in many countries, setback zones are increasingly used (e.g. Australia, New Zealand, The Netherlands, Cuba), following the awareness that, protection structures will not cost-effectively mitigate SLR impact in all the developed areas, and somewhere retreat may be the only feasible option in the longer term (Cummings *et al.* 2012).

In several countries, the central government formulated guidelines to help local communities to produce management plans based on sound scientific data, e.g. New Zealand Ministry for the Environment (2017), California Coastal Commission (2018).

At Varadero (Cuba), hotels retreat behind the dunes showed its benefit when hurricane Irma hit the coast: no permanent beach erosion and damages to the structures were produced in the sectors where realignment was completed, where severe impacts occurred in the unmodified sectors (CITMA 2017).

In Croatia, combining protection and construction restriction in undeveloped areas, future coastal flooding cost could be reduced by up to 39%, and if managed realignment is included, reduction can be up to 93%

RIQUALIFICAZIONE E ADATTAMENTO DEL WATERFRONT ALL'INNALZAMENTO DEL LIVELLO DEL MARE. L'esperienza della principale meta turistica del litorale italiano (Rimini)

L'effetto combinato della risalita eustatica e della subsidenza delle pianure costiere rappresenta una grave minaccia per gli insediamenti litoranei. In prospettiva gli eventi di inondazione marina aumenteranno in frequenza ed entità, esacerbando le potenziali perdite economiche e i costi di adattamento. In Italia, una importante quota di popolazione e di attività economiche si trova lungo la bassa pianura costiera della costa nord adriatica, una delle più sensibili alle variazioni relative del livello del mare. Nei prossimi decenni, queste variazioni indotte dal riscaldamento climatico diventeranno il primo fattore di rischio di inondazione costiera.
Il Comune di Rimini, con il progetto "Parco del Mare" si è posto l'obiettivo combinato di riqualificare il lungomare e di mettere in sicurezza la città dagli eventi meteo marini intensi previsti sempre più frequenti per le prossime decadi. Si tratta di un grande progetto di rigenerazione di tutto il waterfront meridionale di Rimini che vede la ricostruzione della duna costiera in raccordo con l'innalzamento della quota del lungomare, che viene rinaturalizzato e dotato di nuovi servizi per il turismo, il benessere, l'ambiente e la mobilità sostenibile.
Il pericolo di inondazione e il danno economico sia per scenari difesi che non difesi, ovvero in presenza o meno del "Parco del Mare" sono stati valutati, grazie alla piattaforma SaferPLACES, sviluppata nell'ambito di un progetto finanziato dall'EIT-ClimateKIC, e sono stati valutati, attraverso l'analisi costi/benefici, i relativi vantaggi in termini di riduzione del danno atteso. I risultati suggeriscono una redditività complessiva nel tempo del progetto, con benefici crescenti dovuti alla maggiore probabilità del verificarsi di intensi fenomeni meteo marini e alluvionali nel prossimo futuro, rappresentando un esempio applicabile, con i necessari adattamenti, ad altre aree urbane costiere in condizioni analoghe, dove una strategia di arretramento risulti pressoché impossibile da perseguire.

(Lincke *et al.* 2020).

However, stakeholder views are more negative on the outcomes of the managed retreat, as a flood risk management strategy, than those of researchers, consultants, and practitioners (Esteves *et al.* 2014).

This creates a gap between what land managers should decide and how much stakeholders are willing to accept, as evidenced by the conflicts triggered by the establishment of a setback line in the city of Cape Town, South Africa (Cartwright and Taylor 2015), or the heated discussion in act in Fairbourne, Wales, opposing the 'Hold the line' and the 'No active intervention' parties (Williams 2018).

In view of the time required to implement a wide scale strategic retreat, which requires heavy investment and full sharing with the population, possibly obtainable with a wartime mentality, it must be planned long before the effects of the SLR can manifest (Lonsdale *et al.* 2008), therefore, when who pays gets no direct benefits.

A full managed retreat is almost impossible in large coastal towns, which are a significant part of the 32% of areas to be defended. Here several flood mitigation projects have been realised yet or are in progress (e.g. Venice, London, Hamburg, Boston, Hong Kong); generally based on surge barriers, artificial dunes, and land elevation, they are frequently flanked by sea walls that sharply separate the sea from the land. However, the concept of a sponge city has been introduced where flood water storage is applied (Shao et al. 2016). The effectiveness of these solutions has been assessed with numerical models, e.g. at Boston, where The National Institute of Building Sciences (NIBS, 2019) estimates that every $1 of federal grants spent on mitigation saves $6 in recovery costs after an extreme event.

Dikes sharply separating the land from the sea cannot be proposed for important coastal tourist destinations, whose economy is fully based on the presence of a beach, where cost / benefit analyses should be performed, like that done on a regional scale in Catalogna, in areas with a high tourist-seaside intensity (Garola *et al.* 2022) to identify where implementing adaptation measures would have the best cost-benefit ratio and introducing instruments, such as a tax / fiscal instrument, to distribute the costs also among the stakeholders according to the benefits received. Similarly, the need to maintain the beach as a recreational resource and enable residents to continue living with a socially acceptable level of risk from flooding has been ascertained for the Gold Coast, Australia (Cooper and Lemckert 2012).

Here 'hold the line' means 'hold the beach', an approach requiring periodic beach nourishment over the selected time scale to maintain the beach profile with the future sea level (Agulles *et al.* 2021), thus sand sources should be assessed, and fill cost considered in the administration's budget (Cooper and Lemckert 2021). This in a strongly competitive marked, if the global share of erodible coast that is nourished will increase from about 3% in 2000 to 18–33% in 2100 as suggested by Hinkel *et al.* (2013).

COASTAL VULNERABILITY AND PLANNING IN EMILIA-ROMAGNA

The morphological characteristics of the regional coastal area, low sandy beaches and low lying coastal plain behind, together with land subsidence and a widespread erosion process along the coast, are highly predisposing factors of the marine flooding risk for the territories and coastal urban areas. The medium elevation on average sea level characterising the 110 km of the regional beaches is less than 2 m for 81% of its total extension, of which more than a half is below 1.5 meters. The coastal dunes are discontinuous, even where present -mostly in Ferrara and Ravenna coastal stretches-, or practically absent -Forlì Cesena and Rimini coasts-, because of the intense anthropic transformation of the coastal areas occurred in the 20° Century. Coastal territories and urban areas floodings have been registered, and may occur more frequently by climate change effects, in occasion of intense storm surges accompanied by 'high water' events, often combined with intense rainfall and river floods (GIDAC Strategy document, part A.2- Knowledge Framework, Emilia-Romagna Region 2022).

The national Law (Legislative Decree 49/2010, implementing the Flood Directive 2007/60/EC) introduced marine floods among the phenomena to be evaluated and managed to reduce the consequences on people and territories. The hazard and risk maps of the PGRA (Risk Flood Management Plan 2021) adopted by the Po River District Basin Authority implementing the Flood Directive, report in the 14 coastal municipalities of Emilia-Romagna of a total area of about 1,512 hectares floodable by frequent meteo-marine events (RP=10 yrs), of 3,040 floodable hectares by infrequent events (RP=100 yrs), and of 7,879 hectares by rare events (RP > 100 yrs).

For the territory of the municipality of Rimini, the hazard maps of marine flooding identify about 168 hectares floodable for frequent events, 239 hectares for infrequent events and 373 hectares for rare events. In a territory with a high density of population, infrastructures, and economic activities on the coastal strip, as Rimini is, this means a very high damage potential in near future climate scenarios.

The Emilia-Romagna regional Act on urban planning (LR 24/2017) promotes and supports municipalities in producing and adopting planning instruments (General Urban Plan) according to adaptation, sustainability, and integration criteria. It identifies among the fundamental principles, the containment of land consumption, the prevention and mitigation of hydrogeological instability events, the regeneration of urbanised territories along with the mitigation and adaptation strategies to climate change.

The multi-objective intervention of the Parco del Mare di Rimini responds to these principles by facing both the present situation and the challenge of climate change by combining the reduction of vulnerability and increase of resilience with the regeneration of the waterfront and the improvement of urban quality, in a territory in which a retreat strategy of buildings is practically impossible to pursue, representing in fact an example for other coastal urban areas in similar conditions.

"PARCO DEL MARE" CASE STUDY: A PROJECT FOR COASTAL FLOOD RISK RESILIENCE

The "Parco del Mare" is a wide regeneration project of the Rimini waterfront, a green-based infrastructure for coastal flooding risk mitigation which also aims to create a new landscape between the city and the sea, through nature, functional to the concept of life quality and safety in the coastal town.

The whole work involves 9 main stretches which together form the so-called Lungomare Rimini Sud, a total of 7.5 km from the south pier of Rimini's port (fig. 01). This division is motivated by the fact that every single stretch has been strongly characterised over time and has, in the imagination of long-time residents and tourists, well-defined characteristics and vocations.

The stretches, from north to south, are: Stretch 1 Lungomare Fellini - Kennedy; Stretch 2 Lungomare Kennedy - Tripoli; Stretch 3 Lungomare Tripoli - Pastures; Stretch 4 Lungomare Pascoli - Firenze; Stretch 5 Lungomare Firenze - Gondar; Stretch 6 Lungomare Murri; Stretch 7 Lungomare Marebello - Rivazzurra; Stretch 8 Lungomare Spadazzi; Stretch 9 Lungomare Spadazzi - Bolognese.

The Sea Park's guiding principles are naturalisation and a move towards creating more open-air living spaces, meeting what are now essential needs and requirements, by placing the focus firmly on wellness, environment, and sustainable mobility (figs. 02-03).

The work, partly already completed and partly in progress, has started from the two apexes of the promenade and has already transformed the Marina Centro promenade (from Rimini's port to Kennedy square) and the Spadazzi promenade in Miramare.

In the part already realised, the fracture between the city and the sea, grown together with the urban development in the last century, is now mended by the reconstruction of the dune, completed with native coastal vegetation, the elevation of the promenade, the realisation of an underground rain-fluvial waters retaining basins, thus protecting the territory from combined weather-marine

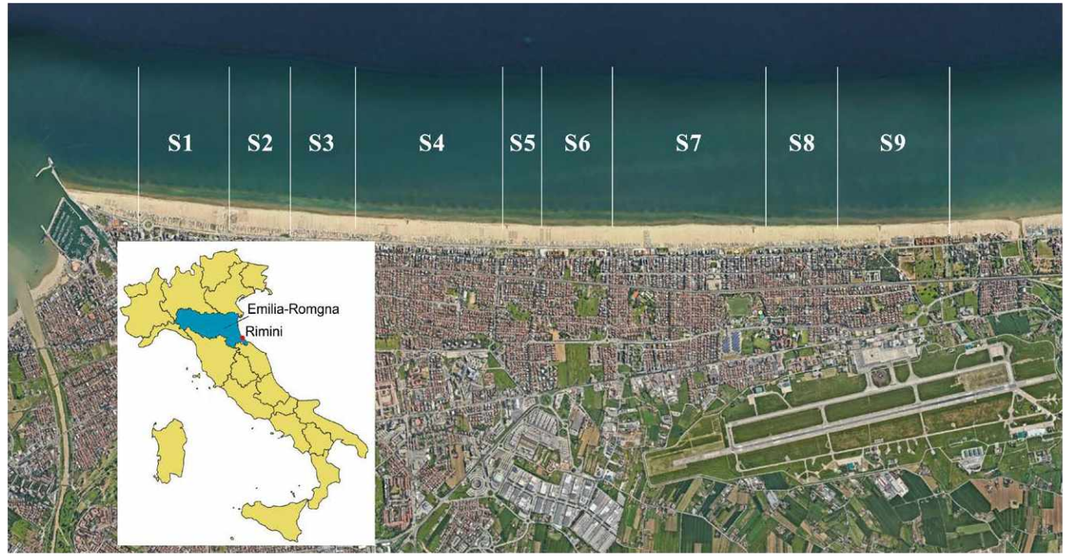

Fig. 01_ Location map and stretches in which the whole project has been divided, basemap © Google Maps 2020

Fig. 02_
Above, Prototype of the "Parco del Mare" showing the requalification project of the whole Rimini southern waterfront. Render made by Stefano Bagli

Fig. 03_
On the right, Picture shot from North to South of the 1st stretch completed, southward of Rimini harbour. Foto by the Municipality of Rimini 2021

events. Moreover, freeing the waterfront from driveways in favour of pedestrian and cycle routes and fitness public stations, are definitively transforming the area into a new place of great attractiveness and environmental quality, for rest, sport, and leisure activities, both for residents and tourists.

Retreat of tourist structures is envisaged and strongly promoted by the Municipality that foresees its progressive implementation in the frame of the requalification projects of beach facilities by the concessionaires, moving landward, with the aim of expanding the dry beach, which will better dissipate wave energy during extreme events.

Financed by municipal, regional and national funds as a multi-objective project, the "Parco del Mare" operation is today under implementation by 9 executive steps, started from the first stretch south of Rimini harbour and the number eight completed in 2020-21, and the stretches number 2 and 3 completed in July 2022. Funding of € 20 million has also been obtained under the PNRR to carry out the works on stretches number 6, 7 and 9, which will start in 2023.

RATIONALE, MATERIALS AND METHODS

In the context of SaferPLACES (saferplaces.co) an EIT-CLimateKIC EU funded research project from 2018 to 2021, the Rimini Municipality developing the Parco del Mare project as urban regeneration plan, has been involved in the implementation and development of the Rimini Pilot.

The SaferPLACES cloud web platform provides a cost-effective and user-friendly cloud-based solution for assessing flood hazard/risk and supports urban planners in designing and testing flood/climate mitigation measures in urban areas. The flood intelligence underlying the SaferPLACES platform integrates the following main components: 1) a Digital Twin automatic generator able to exploit the available big open climate and geospatial data (Copernicus, Google Earth Engine, Amazon, Open Street Map), 2) innovative AI-based and fast DEM-based flood hazard assessment methods with Bayesian damage models, which are able to provide results in short computation times 3) the power and scalability of cloud computing. The platform addresses pluvial, fluvial, and coastal flood hazards and risks assessment in urban and peri-urban environments under current and future climate scenarios, enabling users to rapidly simulate the effect of mitigation measures (i.e., reduction of flood-losses).

The project aims to improve the seafront promenade with greener areas, new sidewalks and in particular with an elevated coastal defence system to protect the cities from current and future coastal flooding events. In fact the sidewalk along the promenade is foreseen at 2.85 m asl (1.00 m higher than the present one) acting as a physical barrier for coastal flooding events.

Thanks to the innovative model embedded in the SaferPLACES platform it is possible to assess the flood hazard and compute the damage assessment in the un-defended (pre Parco del Mare) and defended scenarios.

Before computing the flood hazard and damages, it has been characterised the Extreme Sea Level (ESL) starting from existing analysis of ESL events occurring on the regional coast (Perini *et al.* 2011, 2016, 2017), which have been adopted by the Regional Environmental Agency to define the official coastal flood hazard zones and related protection standards (ARPA Emilia-Romagna 2019). The probability of occurrence of these ESL scenarios is expressed in terms of Return Period (RP), which is the estimated average time interval (in years) between events of similar intensity. Four scenarios of increasing intensity are designed, namely RP 1, 10, 100 and 250 years. For each of these hypothetical scenarios, the Total Water Level (TWL) nearshore is calculated as the sum of extreme values for Storm Surge level (SS), max Tide (Tmax) and Wave contribution (Wc) at each time-step (see Table 01).

Moreover, the future scenarios in terms of ESL have been evaluated considering the contribution of Sea Level Rise (SLR) and Land Vertical Movement (LVM) projections.

The projections of future MSL account for sea thermal expansions from four global circulation models, estimated contributions from ice sheets and glaciers (Hinkel *et al.* 2014) and long-term subsidence projections (Peltier, 2004). The ensemble mean is chosen to represent each Representative Concentration Pathway (RCP) for different time slices. The increase in the central Mediterranean basin is projected to be approximately 0.2 m by 2050 and between 0.5 and 0.7 m by 2100, compared to historical mean (1970-2004) (Vousdoukas *et al.* 2017). As agreed with local stakeholders (Comune di Rimini), our analysis considers the intermediate emission scenario RCP 4.5, projecting an increase in MSL of 0.53 m at 2100.

Average subsidence rates observed for 2006-2011 along the Emilia-Romagna coast are around 5 mm/yr, exceeding 10 mm/yr in the back shore of the Cesenatico and Rimini areas and topping 20-50 mm/yr in Ravenna (Perini *et al.* 2017; Carbognin *et al.* 2009). Based on these current rates, we assume an average fixed annual VLM of 5 mm in Rimini up to the end of the century.

Tab. 01_
Components of nearshore TWL for four ESL scenarios (RPs) designed according to analysis of historical ESL events and projected MSL change (2050 and 2100), accounting for both SLR (RCP 4.5) and average LVM rate

	Extreme event features					Historical	2050			2100		
RP years	SS (m)	Tmax (m)	Wc (m)	Time (h)	Wp (s)	TWL (m)	SLR (m)	LVM (m)	TWL (m)	SLR (m)	LVM (m)	TWL (m)
1	0.60	0.40	0.22	32	7.7	1.22	0.14	0.19	1.55	0.53	0.44	2.19
10	0.79	0.40	0.30	42	8.9	1.49	0.14	0.19	1.82	0.53	0.44	2.46
100	1.02	0.40	0.39	55	9.9	1.81	0.14	0.19	2.14	0.53	0.44	2.78
250	1.40	0.45	0.65	75	11	2.50	0.14	0.19	2.83	0.53	0.44	3.47

THE OUTPUT OF THE COASTAL FLOOD HAZARD MODEL

The model output consists of a set of inundation simulations that include several hazard intensity variables in relation to flood extent: water depth, flow velocity, and duration of submersion.

ESL scenarios are then summarised into static maps, each one representing the maximum value reached by hazard intensity variables during the simulated event at about 1 meter resolution (Amadio 2022). The flood extents corresponding to each RP scenario are shown for Rimini (fig. 04).

In Rimini, the Parco del Mare barrier produces benefits in terms of avoided flooding in the south-eastern part of the town (high-density area) for ESL events with a return period of 100 years or less (fig. 05).

The north-western part and the marina are outside of the protected area; these areas are therefore subject to a similar amount of flooding across scenarios. In all the simulations, the buildings located behind the marina are the first to be flooded. In fact, the new and the old port channels located on both sides of the marina represent a hazard hotspot as shown in the maps, the failure of the eastern channel, which has a relatively low elevation, is likely to cause the water to flood the eastern part of the town, even during inundation events that would not overpass the beach. In the "defended" scenarios, where both the coastal and the canal barriers are enabled, the flood extent in the south-eastern urban area becomes almost zero for ESL events with a probability of once in 100 years, even when accounting for SLR up to 2100. Under the most exceptional ESL conditions (RP 250 in 2100), the barrier is overtopped, generating a flood extent similar to the baseline scenario for the same occurrence probability.

Fig. 04_ Rimini, extent of land affected by flood according to frequency of occurrence of ESL event up to 2100 for the baseline [left] and the defended scenario [right]. Basemap © Google Maps 2020; elaboration by Amadio 2022

RISK MODELING AND DAMAGES

Direct damage to physical asset is estimated using a customary flood risk assessment approach originally developed for fluvial inundation, which is adapted to coastal flooding assuming that the dynamic of impact from long-setting floods depends on the same factors, namely: 1) hazard magnitude, and 2) type, size and value of exposed asset. Indirect economic losses due to secondary effects of damage (e.g. business interruption) are excluded from the computation.

The Expected Annual Damage (EAD) is calculated as a function of maximum exposed values and submergence value. In Rimini, the EAD grows from around 650 thousand Eur under historical conditions to 2.8 million Eur in 2050 and more than 32.3 million Eur in 2100. Under less severe ESL scenarios (RP below 100 years), the risk remains mostly confined around the marina, which is located outside the defended area, producing an expected damage below 10 thousand Eur. Under more extreme ESL scenarios, the benefits of the Parco del Mare project protecting the southern part of Rimini become more evident, avoiding about 65% of the expected damages in the defended scenarios compared to the undefended ones. The damage avoided in the defended scenarios grows almost linearly with the increase of the baseline EAD under future projections of sea level rise: under the defended scenario, the EAD is reduced on average by 45% in comparison with the undefended scenario (fig. 06). The project produces benefits up to scenario RP 250 years in 2100, where a projected TWL of 3.5 meters would cause the overtopping of the barrier, reducing the benefits to almost zero (fig. 07).

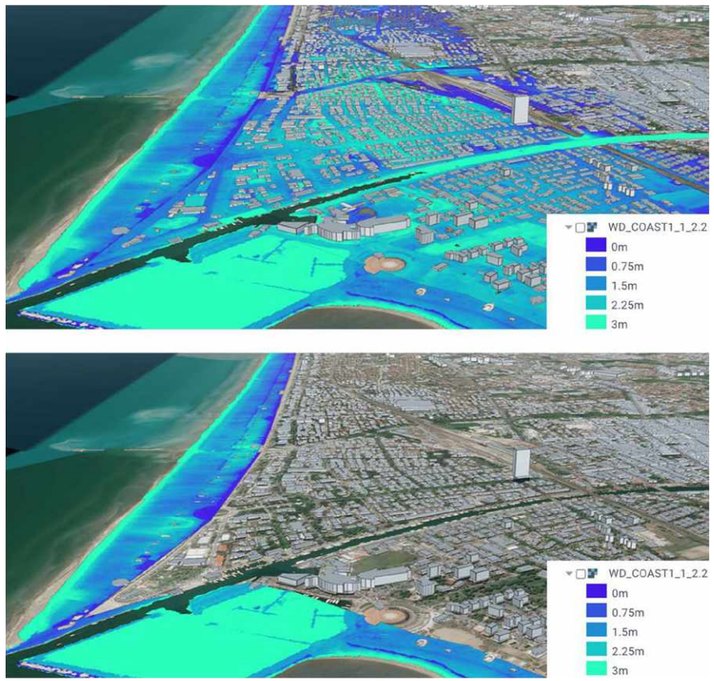

Fig. 05_ Coastal Flooding Extension, year 2050, without (above) and with "Parco del Mare" (below)

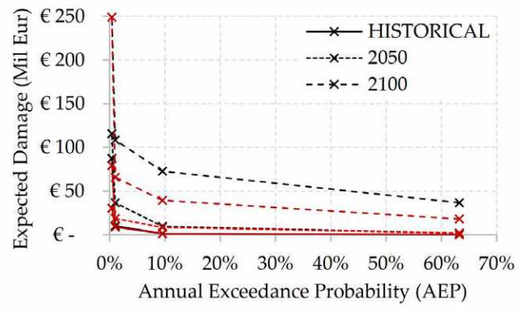

Fig. 06_ Rimini, Expected Annual Damage (EAD) according to undefended scenario up to 2100, all town considered; elaboration by Amadio 2022

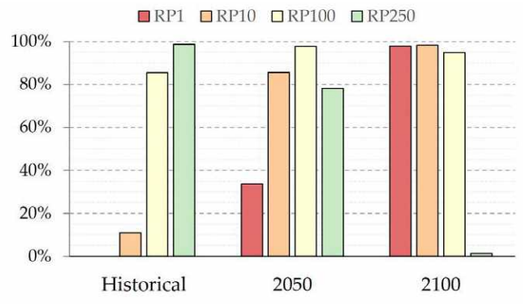

Fig. 07_ EAD reduction in the south-eastern part of the town thanks to hazard mitigation offered by the coastal barrier; elaboration by Amadio 2022

CONCLUSIONS

The operation of the "Parco del Mare di Rimini" involves aspects of adaptation and enhancement of the city's resilience to the climate change scenarios, in combination with regeneration of urban-architectural assets, including cost-benefit analysis and citizen and stakeholders' engagement guiding the decision-making process. The quantitative assessment has been developed using the SaferPLACES platform, an innovative Digital Twin Solution for flood risk intelligence in urban areas, developed in the framework of an EIT CLIMATE-KIC funded research project (saferplaces.co).

It is a concrete experience, still under implementation and to be completed in the next few years, in line with the European, national and the regional (Emilia-Romagna) regulatory framework and financed by municipal, regional and national funds, that can be compared with main international case studies where flood mitigation projects have been realised or are in progress (e.g. Venice, London, Hamburg, Boston, Hong Kong).

Unfortunately, the Sea Park Implementation works, even in the completed sections, have not been implemented on the beach, and therefore it is not yet possible to fully assess the effects of the marine ingression mitigation works. It is true that it represents a long process involving the entrepreneurial activities on the beach necessarily to be fostered and governed by the Municipality during and after completion of the interventions, but it's also true that the multi-objective operation Parco del Mare is today a fundamental step towards a safer future of the town in relation to climate change and SLR, also matching with objectives of regeneration and attractiveness re-launching of the tourist destination.

Together with interventions aimed at improving the life quality of residents and tourists, with a greener and more sustainable environment, Rimini is completely changing its waterfront so that the term 'riminization', entered the international literature to negatively describe a kind of coastal urbanisation, will soon acquire a new positive meaning.

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EROSIONS

SEA LEVEL RISE AND COASTAL EROSION IN THE MEDITERRANEAN BASIN

As at the departure for a long journey one prepares to discover new places, new stories and people, so begins the journey of "Seascape. International journal of Architecture, Urbanism and Geomorphology of coastal landscapes". It aims to serve as an international reference for the exchange of knowledge and experiences regarding issues and problems affecting the world's coastal areas.
Urban Planning, Architecture, Landscape Architecture, Geomorphology, Ecology, Botany and Archaeology find in Seascape a space for discussion, aimed at the advancement of scientific research and dissemination, as an opportunity for the production and transfer of a "new culture of design " sensitive to contemporary contingencies.
For these reasons, non-academic realities such as research centers, companies, associations and territorial bodies also participate in building a "bridging journal" between the world of scientific research, governance and the community.

This first issue of Seascape addresses the topic of coastal erosion in the Mediterranean basin, with a particular focus on the Italian coasts. The acceleration of this phenomenon is among the most worrying effects also exacerbated by climate change. The transformations affecting Mediterranean coastal landscapes are particularly evident and at times alarming, because of rising sea levels, the increasingly frequent alternation of tides, winds and rainfall, and the anthropic actions.
Illegal buildings and inadequacy of techniques and technologies used so far for mitigation have contributed, paradoxically, to increasing erosive stresses, disrupting landscapes, erasing unique identities and characters.
Seascape 01 has gathered research, planning and design experiences to identify and analyze past mistakes; to draw a possible strategic line to live with the ongoing phenomena, between adaptation actions and managed retreat, before further physical, economic and social heritage will be lost forever.

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