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TATTICHE DI RESILIENZA PER AMBITI URBANI COSTIERI
La Marina di Latina e il Porto di New York

RESILIENCE TACTICS FOR COASTAL URBAN AREAS
The Marina di Latina and the New York Harbour

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ABSTRACT

Il contributo presenta nuovi riferimenti teorico-metodologici per la pianificazione urbanistica delle aree costiere finalizzati al potenziamento dei processi di adattamento ai cambiamenti climatici, attraverso la definizione e l'implementazione di macro-strategie di resilienza urbana. La ricerca, basata su sperimentazioni condotte in contesti americani e italiani, evidenzia la vulnerabilità e la suscettibilità delle aree costiere urbane ai rischi idraulici associati ai cambiamenti climatici, come gli eventi estremi e l'innalzamento del livello del mare; lo studio riporta anche i risultati degli attuali progetti pilota che stanno sperimentando le macro-strategie. I risultati sottolineano l'importanza di adottare approcci integrati, multidisciplinari e interscalari per la trasformazione e la protezione delle aree urbane costiere.

The contribution presents new theoretical and methodological frameworks for urban coastal planning to enhance climate change resilience processes by defining and implementing urban resilience macro-strategies. The research, based on experiments conducted in both American and Italian contexts, highlights the vulnerability and susceptibility of urban coastal areas to hydraulic risks associated with climate change, such as extreme events and sea level rise. The study also reports on the results of current pilot projects testing these macro-strategies. The findings underscore the importance of adopting integrated, multidisciplinary, and interscalar approaches for the transformation and protection of urban coastal areas.

KEYWORDS

cambiamento climatico, pianificazione locale, rigenerazione urbana, resilienza climatica, soluzioni basate sulla natura

climate change, local planning, urban regeneration, climate resilience, nature-based solutions

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L'articolo presenta i risultati di ricerche e sperimentazioni[1] condotte dagli autori sulle macro-strategie di rigenerazione urbana in aree vulnerabili per il cambiamento climatico, combinando misure di adattamento, processi dinamici e sviluppo sostenibile. L'oggetto e le motivazioni della ricerca affondano le radici nelle profonde trasformazioni fisiche e sociali che hanno interessato le città e i territori contemporanei negli ultimi decenni (Magni and Musco, 2017).

Questi cambiamenti sono stati determinati da una serie di eventi sociali, politici ed economici e sono caratterizzati da significative dicotomie sulla scena internazionale, come la progressiva crescita demografica globale (UN-HABITAT, 2022, 2016), cui si contrappone il recente 'inverno demografico' osservato in Italia dal 2008, ultimo anno in cui la popolazione nazionale ha registrato un aumento rispetto all'anno precedente (ISTAT, 2022, 2024). A queste dinamiche si aggiungono gli impatti dei cambiamenti climatici (IPCC, 2023), l'esaurimento delle risorse ecologiche ed energetiche e la continua perdita di biodiversità (European Commission, 2019, 2020), fattori che hanno resa necessaria la riflessione sull'urgenza di definire strategie di adattamento e mitigazione del clima con l'obiettivo di rendere le città più resilienti e sostenibili (European Commission, 2013), come auspicato dagli Obiettivi di Sviluppo Sostenibile dell'Agenda 2030 (UN, 2015a, 2015b), in particolare l'Obiettivo 11 (Città e comunità sostenibili) e l'Obiettivo 13 (Azione per il clima).

In questo contesto si evidenzia anche il quadro normativo nazionale di riferimento per guidare l'attuazione di azioni volte a ridurre i rischi determinati dai cambiamenti climatici (UNISDR, 2013, 2015), migliorare la capacità di adattamento dei sistemi naturali, sociali ed economici e sfruttare le opportunità che possono derivare dalle nuove condizioni climatiche, in conformità all'obiettivo del PNACC (Piano Nazionale di Adattamento al Cambiamento Climatico; MASE, 2023).

Mentre nel contesto europeo la risposta alle sfide urgenti e complesse del nostro tempo è perseguita attraverso missioni, strategie e obiettivi comunitari (Directorate-General for Research and Innovation – European Commission, 2020), negli Stati Uniti l'Inflation Reduction Act (Bistline et alii, 2023) rappresenta l'investimento più significativo nella transizione energetica e nella resilienza climatica, insieme all'Infrastructure Investment and Jobs Act (Bertrand, 2022), che sostiene gli investimenti nelle infrastrutture verdi. A livello locale, a New York le sfide climatiche sono affrontate attraverso il PlaNYC (The City of New York, 2023), con particolare riferimento a eventi estremi come inondazioni e tempeste costiere (Braneon et alii, 2024).

Stato dell'arte | Il campo di indagine riguarda le aree urbane costiere soggette a inondazioni – previste fino al 2100 – causate dagli effetti combinati del progressivo innalzamento del livello del mare (SLR) e di eventi alluvionali sempre più frequenti, entrambi innescati dall'aumento della temperatura media globale (IPCC, 2023). I contesti territoriali di riferimento, illustrato nei due casi studio analizzati, sono il litorale laziale, identificato dall'ENEA come una delle 33 aree italiane maggiormente a rischio di compromissione entro il 2100 a causa del fenomeno SLR (Antonioli et alii, 2017), e il Porto di New York, con il sito di Governors Island, soggetto a inondazioni a causa di fenomeni di marea. In relazione alla specificità di ciascuna area i risultati della ricerca hanno delineato tre strategie di resilienza urbana contro il SLR e le inondazioni: difesa, adattamento e delocalizzazione attraverso la definizione di un toolkit di azioni a prova di clima e specifici del sito, che privilegia l'uso di soluzioni basate sulla natura (Mariano and Marino, 2019, 2022b).

La strategia di difesa si riferisce alla necessità di proteggere il territorio dalle minacce del cambiamento climatico, laddove queste rappresentino un rischio tangibile per la sicurezza della popolazione, attraverso opere di ingegneria idraulica e di protezione (dighe, barriere, oggetti, ecc.). La strategia di adattamento riguarda la necessità di 'adattare' la forma urbana ai modelli e alle proiezioni di cambiamento, tenendo conto del contesto ambientale e attuando azioni di riconfigurazione morfologica che privilegino la flessibilità e la diversità (Mariano et alii, 2021).

La strategia di delocalizzazione invece è la più radicale e ancora poco indagata; essa prevede il dislocamento degli insediamenti più vulnerabili in aree geomorfologicamente più sicure, nei casi in cui il rapporto tra costi-benefici delle misure di difesa e adattamento non sia ritenuto economicamente sostenibile (Ryan, Vega-Barachowitz and Perkins-High, 2015). Questa strategia apre scenari complessi che richiedono la valutazione di modalità di delocalizzazione e degli ambiti di nuova ricollocazione, affrontando anche il tema del recupero e della rigenerazione delle aree liberate dalla pressione insediativa attraverso progetti di ripristino ambientale su larga scala.

Metodologia | La metodologia applicata ai casi studio, organizzata in fasi operative, è finalizzata alla comprensione delle complesse dinamiche legate ai fenomeni di rischio idraulico causati da inondazioni e SLR nell'ambito di uno scenario di emissioni SSP5-8.5 in una specifica area target. Ciò consente di contestualizzare, definire e successivamente implementare le tre macro-strategie di resilienza urbana di difesa, adattamento e delocalizzazione attraverso l'esplicitazione di azioni site-specific e climate-proof capaci di guidare la transizione resiliente delle aree urbane costiere. Le fasi operative sono strutturate in: 1) definizione del quadro conoscitivo del rischio idraulico; 2) analisi e valutazione qualitativa-quantitativa; 3) pianificazione; 4) progettazione e sperimentazione; 5) monitoraggio a breve, medio e lungo termine.

Nel primo caso studio di Marina di Latina (LT) la prima fase operativa prevede la definizione del quadro conoscitivo del rischio idraulico in una specifica porzione di territorio individuata come area target; ciò avviene attraverso la creazione preliminare di una mappa di rischio per il SLR proiettata all'anno 2100. A tal fine sono state estratte le curve altimetriche dal DTM (Digital Terrain Model) LiDAR con una risoluzione di 2 metri – mentre le altre analisi di supporto sono state effettuate utilizzando il file DEM (Digital Elevation Model) con una risoluzione di 10 metri – mediante il software QGIS 3.26.3. È stata quindi isolata la curva altimetrica corrispondente a 63 cm sul livello del mare, conforme con la proiezione della linea di costa prevista per il 2100 (Fig. 1), secondo lo scenario di emissione: GHG SSP5-8.5 con proiezioni di 0,20-0,29 metri entro il 2050 e 0,63-1,01 metri entro il 2100 (IPCC, 2023). Dopo aver determinato il rischio idraulico da SLR è stato definito il fattore di rischio associato a fenomeni di precipitazioni intense o esondazioni fluviali. Gli shapefile sono stati acquisiti dalle mappe di rischio e pericolosità incluse nel Piano di Gestione del Rischio Alluvioni (PGRA) prodotto dall'AUBAC (Autorità di Bacino Distrettuale dell'Appennino Centrale).

Secondo l'articolo 6 del Decreto Legislativo 49/2010 (Presidente della Repubblica Italiana, 2010) che attua la Direttiva 2007/60/EC (European Parliament and Council of the European Union, 2007), le mappe della pericolosità e del rischio di alluvione elaborate da AUBAC tengono conto delle potenziali conseguenze negative sul numero di abitanti potenzialmente interessati, del tipo di attività economiche che insistono nell'area potenzialmente interessata, degli impianti ai sensi della Direttiva 96/51/EC (Council of the European Union, 1996) che potrebbero causare inquinamento accidentale in caso di alluvioni, delle aree protette potenzialmente interessate da alluvioni con elevato trasporto solido e colate detritiche e delle informazioni su altre fonti significative di inquinamento.

A supporto della seconda fase operativa, relativa alla valutazione qualitativa-quantitativa di questi fenomeni nell'area target, è stato analizzato il periodo di ritorno associato all'evento climatico (Figg. 2-4), dove per periodo di ritorno si intende il tempo medio in cui un determinato valore di intensità viene eguagliato o superato almeno una volta. In particolare si è fatto riferimento ai periodi di ritorno indicati nel rapporto n. 353/2021 dell'Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA, 2021), nel quale si evidenzia che per le alluvioni fluviali i periodi di ritorno utilizzati nella modellazione all'interno del Distretto dell'Appennino Centrale sono compresi tra i 30 e i 50 anni per lo scenario ad alta probabilità e tra i 100 e i 200 anni per lo scenario a media probabilità (Lastoria et alii, 2023).

Sono stati inoltre valutati lo stato di attuazione dello strumento di pianificazione (PRG), la relazione tra le componenti territoriali sistemiche (sistema ambientale, insediativo e infrastrutturale) e gli eventi climatici associati al rischio idraulico. Queste analisi hanno facilitato l'esplicitazione delle criticità dello strumento di pianificazione circa la risposta al rischio determinato dalle alluvioni, piogge intense, esondazioni fluviali ed erosione costiera da SLR e hanno permesso di individuare macro-strategie per la resilienza urbana che permettono il superamento del tradizionale approccio settoriale a favore di un approccio integrato alla complessità urbana, riconducibile all'approccio ecosistemico (Mariano and Marino, 2022a).

Questo approccio viene ulteriormente sviluppato attraverso un toolkit di azioni site-specific per il rischio idraulico che collega le azioni di progetto selezionate sulla base di un'analisi delle best practices e dei casi di studio di contesti simili alle componenti sistemiche rilevanti per la struttura urbana dell'area di destinazione. Oltre che integrare i sistemi fisico-territoriali con le macro-strategie per la resilienza urbana, il toolkit consente di definire chiaramente i benefici delle azioni, di identificare i principali stakeholder, di stimare i costi di attuazione e di stabilire le tempistiche di intervento, che possono essere a breve, medio o lungo termine.

Il quadro metodologico, precedentemente esplicitato dagli autori in altre ricerche, innova l'approccio procedurale, basato su una logica processuale, iterativa e multi-scalare (Ricci and Poli, 2018), attraverso l'introduzione di un'analisi parametrica del rapporto di incidenza tra i fenomeni di rischio idraulico e le componenti sistemiche dell'area target, considerando sia lo stato attuale che le proiezioni future

Fig. 1 | Definition of the projected new coastline by the year 2100 in the target area, in accordance with the GHG emissions scenario SSP5-8.5, cm 63 projection (credit: F. Ianiri, 2024).

Fig. 2 | Identification of high hydraulic risk areas (flooding and overflow) with a 30-year return period, based on the AUBAC Flood Risk Management Plan (credit: F. Ianiri, 2024).

Fig. 3 | Identification of medium hydraulic risk areas (flooding and overflow) with a 100-year return period, based on the AUBAC Flood Risk Management Plan (credit: F. Ianiri, 2024).

Fig. 4 | Overlay of medium hydraulic risk areas (flooding and overflow) – with a 100-year return period, based on the AUBAC Flood Risk Management Plan – with the projected new coastline by the year 2100 under the GHG emissions scenario SSP5-8.5 (credit: F. Ianiri, 2024).

per gli anni 2053 e 2100. Il confronto dei risultati tra scenari futuri e lo stato attuale fornisce valutazioni qualitative e quantitative a supporto dei decisori politici nell'aggiornamento degli strumenti di pianificazione locale, riducendo i fattori critici legati al rischio idraulico identificati durante l'analisi preliminare. La metodologia sopra descritta è stata applicata sia al caso di studio del Porto di New York che a quello della Marina di Latina.

Il caso di studio della Marina di Latina | La sperimentazione delle macro-strategie di resilienza urbana è stata condotta nell'area target della Marina di Latina (LT), identificata come una delle 30 aree ad alto rischio idraulico (inondazioni, allagamenti e innalzamento del livello del mare) lungo la costa laziale. Questo territorio presenta caratteristiche geomorfologiche uniche, principalmente per la presenza di limo, argilla, sabbia e depressioni del terreno note come 'piscine tirreniche' (Fig. 5). Secondo Stanisci et alii (2001) le piscine sono depressioni tipiche delle aree pianeggianti soggette all'affioramento della falda freatica o ad abbondante apporto di acque meteoriche, associato a suoli argillosi con lento drenaggio che si sono formate poiché la lieve pendenza e le dune lungo la costa hanno ostacolato il deflusso di numerosi corsi d'acqua alimentati dalle sorgenti dei monti Lepini e Ausoni.

La peculiarità del paesaggio è anche definita da uno studio sui suoli della Provincia di Latina che categorizza l'area target nella classe SR4 – Pianure costiere con substrato costituito da depositi marini quaternari e SR9 – Terrazzi conglomeratici sabbiosi, antiche dune 'rosse' (Arnoldus-Huyzendveld, Perotto and Sarandrea, 2009) e segnala la presenza di un raro tipo di suolo chiamato Planosol, in corrispondenza dell'antica duna in questa fascia costiera. Tuttavia i processi di bonifica del territorio all'inizio del 1900 e i processi di antropizzazione spontanea a partire dalla metà del secolo hanno compromesso in modo significativo gli ecosistemi caratteristici della Pianura Pontina e delle 'piscine tirreniche' che circondano l'area target della Marina di Latina.

Questa condizione è sottolineata anche in un rapporto tecnico dell'Agenzia Regionale dei Parchi, finalizzata a identificare nuove aree protette nell'ambiente dunale costiero del Lazio e all'analisi della costa dal punto di vista geomorfologico, vegetazionale e faunistico, individuando i sistemi dunali costieri e valutando il loro grado di naturalità (Fattori et alii, 2010). Nella relazione viene evidenziato come il tratto nel quale è localizzata l'area target, corrispondente all'unità fisiografica numero 4 tra Capo d'Anzio e Capo Circeo, presenta la percentuale più alta di dune antropizzate della costa laziale; ad avvalorare le condizioni di fragilità dell'area vi sono le valutazioni di rischio emerse in fase di analisi, attraverso la composizione del quadro cognitivo.

Durante le indagini preliminari è emerso che la nuova linea di costa prevista per il 2100, nello scenario di emissioni SSP5-8.5, interesserà il 30,04% del patrimonio immobiliare[2] nell'area di interesse (Fig. 6). Nelle aree classificate a rischio medio, corrispondenti a un periodo di ritorno di 100 anni, fenomeni come forti piogge ed esondazioni fluviali interesseranno il 29,18% degli edifici esistenti (Fig. 7), mentre nelle aree ad alto rischio, con un periodo di ritorno di 30 anni, tali eventi interesseranno il 9,61% del totale (Fig. 8).

I risultati delle analisi del rischio devono tenere conto della sovrapposizione di vari fenomeni che potrebbero colpire l'area di interesse, alterando significativamente l'incidenza e il coinvolgimento degli edifici esistenti: nello scenario di emissioni SSP5-8.5 per il 2100 se le inondazioni e le esondazioni fluviali si verificassero contemporaneamente o in finestre temporali ravvicinate il numero di edifici coinvolti aumenterebbe notevolmente, raggiungendo il 56,09% del totale (Tab. 1; Fig. 9).

Per un territorio sub-limen, in transizione, dove i paesaggi del passato, presente e futuro si incontrano e si intrecciano (Marino, 2023), e dove il territorio è 'sospeso' a causa del rischio di una potenziale per-

Fig. 5 | The 'Piscina della Verdesca', located within the 'Cerasella' equipped area in the Circeo National Park (IT), represents one of the well-preserved ecosystems of the Tyrrhenian Forest in the Agro Pontino (credit: F. Ianiri, 2023).

dita, si apre un'opportunità di rigenerazione fisica in chiave ecologica (Mariano and Marino, 2022b), in cui la dimensione di precarietà viene alimentata dalle previsioni di pianificazione e sviluppo urbanistico per l'area target, ad oggi solo parzialmente attuate.

Queste disposizioni prevedono il completamento di circa 477.148 mc su un totale di 636.190 mc (Tab. 2) nella variante del PPE (Piano Particolareggiato Esecutivo) del 1999, approvata[3] nel 1983. L'analisi ha inoltre evidenziato un altro aspetto critico nella pianificazione dell'area di interesse: il perimetro per l'attuazione del PPE nel comprensorio della Marina di Latina copre una superficie di 2.894.966 mq e le aree a rischio idraulico alto e medio si estendono su 1.469.301 mq, occupando il 50,74% della superficie totale, inclusi i terreni situati entro 300 metri dalla linea di costa. Un ulteriore fattore da considerare è la superficie che sarà interessata dall'avanzamento della linea di costa entro il 2100: nello scenario SSP5-8.5 l'avanzamento della linea costiera influenzerà 576.786 mq che, sommati alle aree già identificate come zone a rischio idraulico alto e medio, portano il tasso di incidenza al 70,66% (Tab. 3).

Secondo gli autori, le criticità dello strumento urbanistico derivano dalla discordanza tra i suoi principi e le linee guida per la gestione del rischio, nell'identificazione della fragilità del territorio e nella regolazione e orientamento del suo sviluppo resiliente e del processo di 'transizione strutturata e duratura' (Litt, Businaro and Maragno, 2022). Il Piano Regolatore Generale (PRG) di Latina, adottato nel 1972 e ancora in vigore, appartiene alla famiglia dei Piani di espansione urbana (Campos Venuti and Oliva, 1993), sviluppati nella seconda fase dello sviluppo territoriale italiano, una lunga fase che si è protratta intensamente per oltre trent'anni fino alla fine degli anni '70 (Oliva, 2014); questi Piani non sono in grado di rispondere a sfide contemporanee come quelle poste dal cambiamento climatico nelle aree urbane costiere.

Considerata la fragilità degli ecosistemi costieri e l'assenza di strategie adeguate le previsioni urbanistiche rischiano di aggravare la situazione, aumentando la pressione antropica e compromettendo l'equilibrio del territorio. In questo contesto le soluzioni proposte rappresentano un'opportunità unica per rigenerare le aree urbane costiere, reintroducendo elementi paesaggistici tipici dell'Agro Pontino, come le 'piscine tirreniche', canali e sistemi dunali con la loro flora e fauna. In linea con i principi della Nature Restoration Law del 2024 (European Commission, 2024), queste soluzioni mirano a rendere Marina di Latina più resiliente e unica, valorizzando la sua biodiversità; per questo motivo gli autori propongono di sperimentare macro-strategie di rilocalizzazione e adattamento.

Il caso di studio del Porto di New York | L'estuario del Porto di New York-New Jersey rappresenta un caso studio in cui vengono applicate sistematicamente macro-strategie di resilienza per affrontare i fenomeni di inondazioni costiere urbane e l'innalzamento del livello del mare (SLR[4]). L'Ufficio del Sindaco di New York City ha messo in evidenza i principali rischi climatici della città: ondate di calore, tempeste di marea e costiere, inondazioni causate dalle maree e precipitazioni estreme[5] (The City of New York, 2023). Questa estrema condizione di vulnerabilità del territorio è emersa dopo l'uragano Sandy, il cui impatto e traiettoria attraverso il New York Bight – l'angolo geografico formato dalle coste del New Jersey e di Long Island – hanno causato un devastante innalzamento del livello del mare.

La Regional Plan Association (RPA, 2017) sottolinea che i Governi devono dare priorità agli interventi nelle aree densamente popolate con elevato capitale sociale ed economico, rendendo necessari sia soluzioni naturali che ingegneristiche per proteggere tali regioni dalle inondazioni e dall'innalzamento del livello del mare[6]. A causa delle limitate risorse finanziarie le aree a bassa densità richiederanno un graduale ritiro dalla costa attraverso modifiche alle normative urbanistiche e acquisizioni di proprietà finanziate dalla Pubblica Amministrazio-

Fig. 6 | Identification of existing volumes affected by sea-level rise phenomena related to the projected new coastline by 2100 under the GHG emissions scenario SSP5-8.5, cm 63 projection (credit: F. Ianiri, 2024).

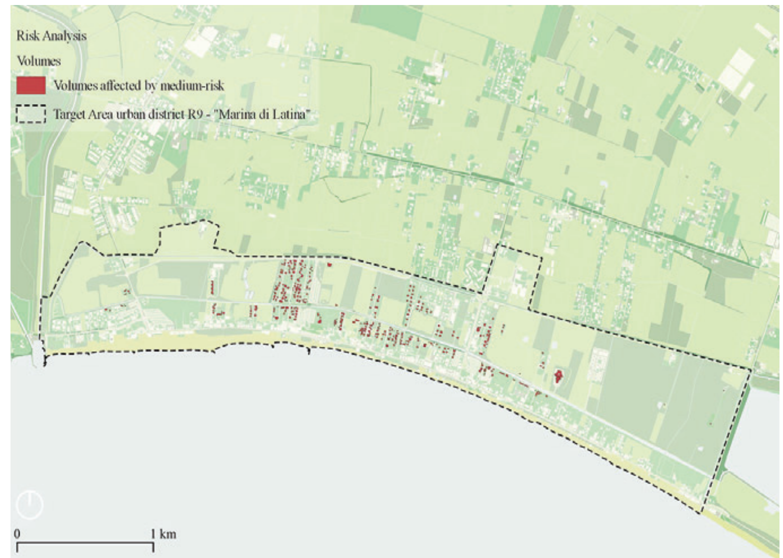


Fig. 7 | Identification of existing volumes located in medium hydraulic risk areas (flooding and overflow), with a 100-year return period, based on the AUBAC Flood Risk Management Plan (credit F. Ianiri, 2024).

Risk phenomenon	Value % of incidence on the total	Buildings	Area m²
Elevated Risk: Return Period 30 years	9.61	135	16,695
Medium Risk: Return Period 100 years	29.18	410	44,881
Sea level rise and coastline 2100 in SSP5-8.5 emissions scenario	30.04	422	52,230
Hydraulic Risk in 2100 (Medium Risk + Sea level rise)	56.09	788	90,167
Reference parameters			
Urban district – Marina di Latina R9	100.00	1.405	176,451

Tab. 1 | Quanti-qualitative reading about the incidence of hydraulic risk and sea level rise in the SSP5-8.5 emissions scenario on the existing buildings (credit: F. Ianiri, 2024).

ne[7]; inoltre l'aumento dei premi assicurativi renderà progressivamente più costoso costruire in aree a bassa quota (RPA, 2017).

L'U.S. Army Corps of Engineers (2022), che ha una vasta giurisdizione nazionale sulle vie navigabili, sui sistemi di protezione dalle inondazioni e sulle normative ambientali, ha proposto diverse soluzioni per il Porto di New York, ciascuna caratterizzata da costi, tempi di realizzazione e livelli di protezione diversi. Lo scenario più estremo prevede l'installazione di muri di contenimento e barriere d'acqua – simili alle barriere MOSE di Venezia – per isolare il Porto di New York dall'Oceano Atlantico e dal Long Island Sound. Il Piano prevede la chiusura di Jamaica Bay e di corsi d'acqua più piccoli, nonché la protezione delle coste nelle aree ad alto rischio[8]. Tuttavia i costi finanziari e ambientali associati a un sistema di barriere marine sono significativi e tale sistema non offre una soluzione all'innalzamento del livello del mare a lungo termine; questo tipo di installazione potrebbe inoltre influire sulla salinità, sulla qualità dell'acqua, sulla sedimentazione e sugli ecosistemi locali; infine la gestione da parte di più Agenzie, il finanziamento da fonti diverse e la definizione di chi risiede dentro o fuori la barriera comportano significative sfide politiche e di gestione (RPA, 2017).

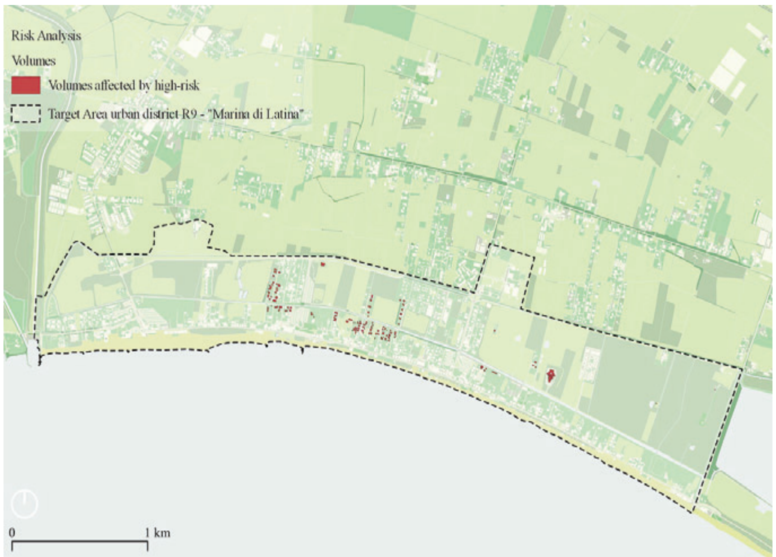
In risposta a queste proposte ingegneristiche i progettisti di New York hanno sviluppato soluzioni di infrastruttura stratificata che integrano spazi pubblici, attività ricreative, componenti educative e habitat per flora e fauna. Gli esempi che si riportano di seguito mostrano un approccio eco-sistemico e multi-scalare, dalla scala territoriale a quella locale e al livello degli oggetti, volto a definire strategie basate sulla natura attraverso diverse discipline progettuali.

On the Water – Palisade Bay è uno studio nato dalla collaborazione di architetti, ingegneri, urbanisti, accademici e studenti che hanno ripensato il quadrante superiore del Porto di New York in risposta all'innalzamento del livello del mare e alle inondazioni causate da eventi climatici estremi[9]. Lo studio mette in discussione il costo, l'efficacia e l'affidabilità delle soluzioni di protezione dalle inondazioni basate su una ingegneria 'pesante', affidate alla realizzazione di muri di contenimento, paratie e dighe, trascurando l'efficacia delle difese naturali, come paludi e zone umide, che possono assorbire l'energia delle maree, tutto ciò anche in relazione al fatto che i fronti 'frastagliati' dei moli delle navi, che mitigavano l'azione delle onde e fornivano habitat, sono venuti meno dopo il trasferimento delle attività portuali dai moli di Manhattan e Brooklyn (Nordenson, Seavitt and Yarinksy, 2008).

Lo studio propone quindi la creazione di 'infrastrutture morbide' che combinano un approccio eco-sistemico alla protezione dalle tempeste, il cui progetto consiste in tre strategie principali: costruire isole e barriere coralline in acque poco profonde per attenuare le correnti delle tempeste, creare una linea di costa varia e porosa con paludi e parchi e aggiornare e integrare le normative di pianificazione urbana per migliorare la resilienza climatica (Nordenson, Seavitt and Yarinksy, 2010). Questo lavoro ha ispirato direttamente la mostra Rising Currents – Projects for New York's Waterfront al Museum of Modern Art, che ha presentato proposte per infrastrutture adattive e 'morbide' nel porto, aumentando la consapevolezza pubblica dei rischi e delle potenziali soluzioni (Bergdoll et alii, 2011; MoMA, 2010).

Nel 2014 il Governo federale ha lanciato il concorso Rebuild by Design (González-Campaña et alii, 2023) per i siti di New York danneggiati dagli effetti dell'uragano Sandy. Lo studio SCAPE, guidato da Kate Orff, è stato premiato per il progetto Living Breakwaters, che prevede l'installazione di frangiflutti ecologici nella Baia di Raritan, al largo della costa di Staten Island: questi frangiflutti interrompono l'azione delle onde, rallentano il flusso dell'acqua e promuovono la sedimentazione lungo le spiagge. Considerando il progetto come parte di un ecosistema più ampio, SCAPE definisce la strategia come un 'approccio stratificato', intrecciando riduzione del rischio, miglioramento ecologico e integrazione della comunità. Fondi statali e federali hanno fornito 114 milioni di dollari per la costruzione di nove frangiflutti, completati nel 2024 (New York State, n.d.).

Le creste dei frangiflutti si estendono verso l'oceano per aumentare la complessità strutturale e ospitare habitat intertidali per pesci, crostacei e molluschi. La zona di sedimentazione a terra fornisce habitat per vongole, fanerogame marine e genera paludi salate, mentre la parte terrestre offre habitat protetti per foche e volatili (Orff, 2016; Fig. 10). L'installazione utilizza una combinazione di rocce, gabbioni e unità prefabbricate di armatura ecologica, ma anche elementi per formare 'piscine di marea'. Il coinvolgimento dei cittadini sarà facilitato attra-



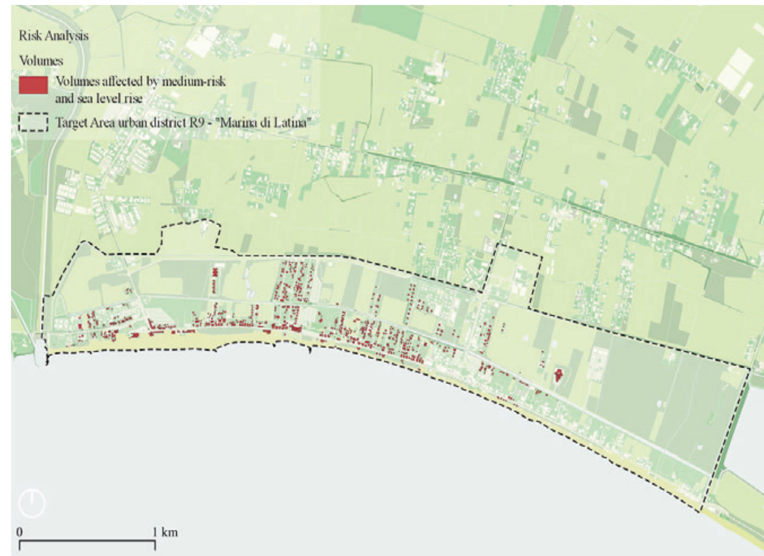


Fig. 8 | Identification of existing volumes located in high hydraulic risk areas (flooding and overflow), with a 100-year return period, based on the AUBAC Flood Risk Management Plan (credit: F. Ianiri, 2024).

Fig. 9 | Identification of existing volumes located in medium hydraulic risk areas (flooding and overflow) – with a 100-year return period, based on the AUBAC Flood Risk Management Plan– and affected by the projected new coastline by the year 2100 under the GHG emissions scenario SSP5-8.5 (credit: F. Ianiri, 2024).

Urban zone	Total of zone	Intended use	Volumes forecast m³	Volumes detected in 2014 m³	Unrealized volumes m³
Expansions zone	12	Residential	474,212	54,208	477,212
		Hotel-type accommodation facilities	57,144	0	
Completion area	6	Residential	28,082	28,082	0
		Hotel-type accommodation facilities	0	0	
Private Green Conservation Areas	36	Residential	76,752	76,752	0
		Hotel-type accommodation facilities	0	0	

Tab. 2 | Analysis of the urban planning forecasts for the R9 Marina di Latina area (credit: F. Ianiri, 2024).

verso il ripristino delle spiagge e la creazione di centri educativi lungo la costa, insieme alla realizzazione del Billion Oyster Project (2019), che mira a reintrodurre un miliardo di ostriche nel porto entro il 2035[10] (Orff, 2016). Come osserva Orff (cit. in Klinenberg, 2021, p. 18) abbiamo passato gli ultimi cento anni a dragare per la navigazione mentre ora, con un clima diverso, abbiamo bisogno di un approccio diverso.

In questo contesto progettuale gli oggetti intertidali arricchiscono il quadro multidisciplinare e multi-scalare con lo scopo di sviluppare linee di costa viventi. Queste installazioni ecologiche promuovono la crescita di specie native e forniscono protezione contro l'erosione, costituendo una componente essenziale di una linea di costa 'stratificata'. Un tale approccio integra vari elementi per garantire la resilienza urbana, combinando componenti ecologiche e ingegneristiche: unità di armatura ecologicamente sostenibili e pannelli di contenimento non solo contribuiscono alla fortificazione costiera, ma migliorano anche l'adattabilità, considerando che molti investimenti esistenti non possono semplicemente essere abbandonati, pertanto è fondamentale integrare le infrastrutture e i progetti esistenti nelle nuove strategie di adattamento e resilienza.

Iniziato come ricerca da Object Territories, uno studio di progettazione con sede a New York e Hong Kong, il progetto è stato successivamente sviluppato presso il Rensselaer Polytechnic Institute (RPI), con la consulenza del CASE (Center for Architecture, Science & Ecology) presso RPI, afterNature con sede a Hong Kong e Fort Miller Group di New York[11]. Il gruppo di lavoro ha stabilito parametri di progettazione, come il fattore di zavorra, la porosità, la tipologia della texture superficiale e la capacità di aggregarsi e interbloccarsi con rocce esistenti o altre unità fabbricate (Figg. 11-13). Quando posizionate in acque intertidali le unità di calcestruzzo tridimensionali possono creare microambienti per creature acquatiche e alghe[12] (Fig. 14): come installazioni esse rappresentano solo una parte di un approccio stratificato necessario per costruire una costa resiliente. Questi progetti dimostrano che un design innovativo può offrire strategie efficaci per mitigare gli effetti del cambiamento climatico nelle aree costiere urbane, pianificare l'adattamento all'innalzamento del livello del mare e ripristinare gli ecosistemi naturali.

Risultati | Grazie all'innovativo processo metodologico sperimentato nel caso di studio di Marina di Latina è stato possibile condurre una duplice analisi qualitativa-quantitativa dell'impatto del rischio idraulico sulle aree urbane previste dal PPE e sulle componenti territoriali sistemiche.

In primo luogo l'analisi ha rivelato che il 49,01% delle aree di espansione individuate dal Piano, ancora non realizzate per le destinazioni d'uso residenziali, sono soggette a rischio medio; su un periodo di ritorno di 100 anni l'impatto del rischio sulle zone urbane ammonta al 50,02%, interessando la metà delle aree in fase di pianificazione (Tab. 4). I risultati ottenuti evidenziano la necessità di attuare un processo di revisione strutturato e integrato del PPE per il Distretto R9 Marina di Latina e delle sue previsioni, revisione che deve basarsi su una comprensione approfondita del territorio, del suo rapporto con il rischio idraulico e dei risultati emersi dall'analisi qualitativa-quantitativa; d'altra parte i risultati dell'analisi del rapporto tra il rischio e le componenti territoriali sistemiche indicano che, nello scenario SSP5-8.5, il sistema ambientale sarà interessato dall'82,37% (Tab. 5), il sistema insediativo morfologico dal 78,79% (Tab. 6) e i sistemi di servizi e infrastrutture dal 27,30% per le componenti areali e dal 43,51% per le componenti lineari (Tab. 7).

I risultati dell'analisi quali-quantitativa hanno fornito un quadro critico che ha guidato la definizione di strategie e azioni progettuali, categorizzate attraverso un toolkit di adattamento ai cambiamenti climatici (Mariano and Marino, 2022a; Tab. 8) e valutate per la loro efficacia di riduzione del rischio tramite una matrice parametrica (Tab. 9). Ogni azione progettuale è stata associata non solo a una macro-strategia per la resilienza urbana e all'obiettivo di resilienza climatica da raggiungere, ma anche esplicitamente allineata a parametri qualitativi e quantitativi, consentendo una valutazione dell'impatto del progetto sull'area target.

Inoltre è stata prestata particolare attenzione all'utilizzo di un approccio eco-sistemico basato sulla natura. Le NbS (Nature-based Solutions), che sfruttano la natura e il potere degli ecosistemi sani per proteggere le persone, ottimizzare le infrastrutture e salvaguardare un futuro stabile e ricco di biodiversità, sono state integrate nelle scelte progettuali (EEA, 2021). Infatti analizzando il toolkit di adattamento ai cambiamenti climatici elaborato per il caso studio di Marina di Latina, tra le NbS selezio-

Zone	Value % of incidence on the total	Area m²
High-Risk Area n.1	4.4	127,309
High-Risk Area n.2	0.57	16,636
High-Risk Area n.3	3.35	97,081
High-Risk Area n.4	6.28	181,662
High-Risk Area n.5	4.00	115,762
High-Risk Area n.6	4.56	132,055
Medium-Risk Area n.1	2.92	8,463
Medium-Risk Area n.2	27.21	787,841
Medium-Risk Area n.3	9.56	276,885
Medium-Risk Area n.4	11.05	319,945
Area related to the projection of the new coastline	19.92	576,786
Total of High-Risk zone	23.16	670,505
Total Medium-Risk zone	50.74	1,469,301
Total Area related to the projection of the new coastline	19.92	576,786
Reference parameters		
Urban district – Marina di Latina R9	100.00	2,894,966

Tab. 3 | Quanti-qualitative reading about the incidence of sea level rise and coastline 2100 in SSP5-8.5 emissions scenario and high and medium-risk zone in the urban district R9 – Marina di Latina (credit: F. Ianiri, 2024).

nate per contribuire al perseguimento degli obiettivi vi sono azioni come la creazione e la riqualificazione di corridoi verdi, l'istituzione di parchi fluviali e il ripristino della componente dunale finalizzati alla riduzione degli effetti dell'erosione costiera.

I risultati del progetto sull'area target di Marina di Latina dimostrano come possono essere implementate strategie integrate di adattamento, rilocalizzazione e 'difesa morbida' (Al, 2018) per raggiungere l'obiettivo della transizione e della resilienza climatica nell'area target.

Nel frattempo la sperimentazione con oggetti intertidali nel caso studio del Porto di New York è iniziata con un progetto pilota che prevede l'installazione di unità progettate da Object Territories e RPI, posizionate a Randall's Island, New York. Una nuova installazione è prevista a Governors Island, con il supporto del Trust for Governors Island nell'ambito della Climate Solutions Challenge (Governors Island, 2024), in attesa dell'approvazione del New York State Department of Environmental Conservation. L'installazione iterativa non ha utilizzato cemento a basso pH, mentre FMG produrrà componenti per la seconda installazione utilizzando sia miscele di cemento standard che a basso pH per valutare le potenziali differenze nel processo di adattamento.

Il team scientifico monitorerà i siti per diversi cicli annuali, documentando lo sviluppo dell'habitat; in termini di efficacia la prima installazione ha già ottenuto risultati veloci[13]: sono bastate poche settimane affinché le piante marine iniziassero a colonizzare gli oggetti, grazie alla natura salmastra delle acque ricche di nutrienti alla confluenza del porto e dell'East River. Questi risultati iniziali sono di auspicio per scenari ottimistici, sebbene gli autori siano consapevoli che conclusioni scientificamente valide richiederanno ulteriori osservazioni prolungate.

Conclusioni | I casi studio presentati evidenziano la natura innovativa della metodologia applicata, che orienta i processi di pianificazione delle aree urbane costiere e ne aumenta la resilienza agli effetti dei cambiamenti climatici. L'approccio multidisciplinare, integrato e interscalare adottato consente una risposta esaustiva e articolata alle sfide emergenti, fornendo una comprensione approfondita delle dinamiche sia locali che globali che caratterizzano i territori contemporanei.

L'analisi quali-quantitativa delle componenti territoriali sistemiche, nonché l'analisi dello stato di fatto e dello stato di diritto, consente di sviluppare soluzioni specifiche capaci di rispondere sia alle esigenze immediate che alle transizioni a lungo termine sostenibili e adattive (Ricci and Mariano, 2022), con modelli metodologici trasferibili e replicabili in contesti simili. I limiti del contributo si possono trovare nella possibilità di integrare ulteriormente nuove tecnologie e approcci nel metodo, come la correlazione tra innalzamento del livello del mare e subsidenza del suolo o la comprensione delle dinamiche legate al fenomeno dell'innalzamento del cuneo salino nel terreno, causata dall'innalzamento del livello del mare, che potrebbero migliorare ulteriormente l'efficacia delle strategie di resilienza urbana, offrendo risposte migliori alle sfide climatiche.

Valutazioni future dell'impatto che gli oggetti intertidali avranno nel creare microambienti per la flora e la fauna acquatica mentre difendono la costa, che è attualmente monitorata e la rendono resiliente, chiariranno ulteriormente i benefici del progetto.

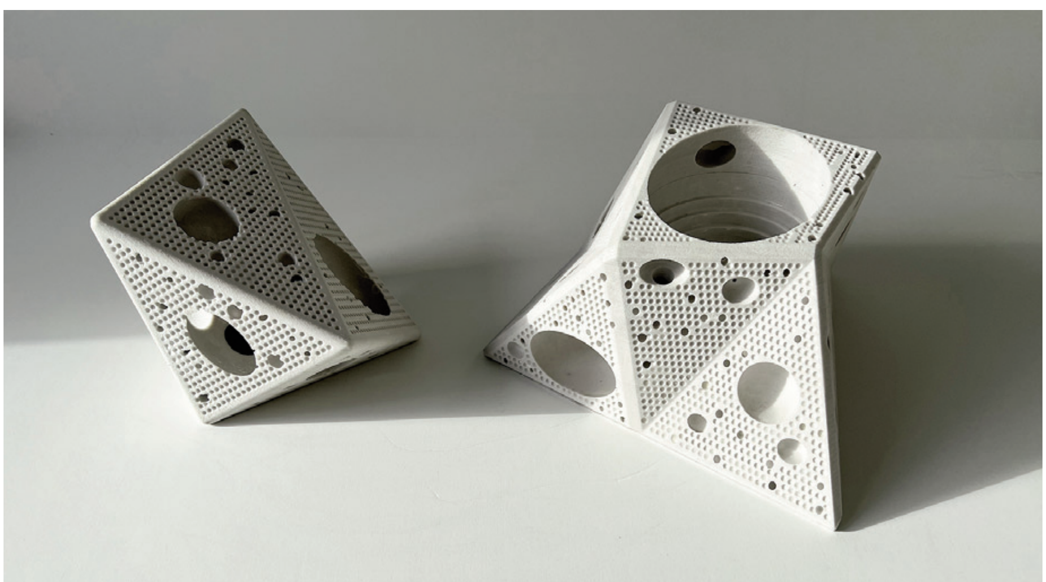
Le sperimentazioni rappresentano un'opportunità per formare, migliorare ed espandere la conoscenza sugli effetti degli interventi progettuali e per definire parametri e indici per la valutazione dei progetti prima della loro implementazione. Il presente contributo si inserisce quindi in un percorso interscalare che va dalla formulazione di macro-strategie di resilienza urbana alla realizzazione concreta di azioni site-specific progettuali alla scala locale, sottolineando l'importanza di un approccio sistemico e interdisciplinare nella pianificazione urbanistica; promuove infine un dialogo continuo tra ricerca e sperimentazione per raggiungere obiettivi di resilienza climatica e sostenibilità ambientale a lungo termine.

This paper presents the findings of research and experimentation[1] conducted by the authors on urban regeneration strategies in climate-vulnerable areas, combining adaptive measures, dynamic processes, and sustainable development. The subject and motivations of the research are rooted in the profound physical and social transformations that have affected contemporary cities and territories over the past decades (Magni and Musco, 2017).

These changes have been driven by a series of social, political, and economic events and characterised by significant dichotomies on the international stage, such as the progressive global population growth (UN-HABITAT, 2022, 2016), contrasted with the 'demographic winter' observed in Italy since 2008, the last year in which the national population recorded an increase compared to the previous year (ISTAT, 2022, 2024). In addition to these dynamics, there are the impacts of climate change (IPCC, 2023), the depletion of ecological and energy resources, and the ongoing loss of biodiversity (European Commission, 2019, 2020). These factors have spurred reflection on adaptation and climate mitigation strategies, with the goal of making cities more resilient and sustainable (European Commission, 2013), as advocated by the Sustainable Development Goals of the 2030 Agenda (UN, 2015a, 2015b), specifically Goal 11 (Sustainable Cities and Communities) and Goal 13 (Climate Action).

There is also a need to provide a national guiding framework for implementing actions aimed at minimising the risks posed by climate change (UNISDR, 2013, 2015), improving the adaptive capacity of natural, social, and economic systems, as well as taking advantage of any opportunities that may arise from new climatic conditions, in accordance with the objective of the Italian PNACC (Piano Nazionale di Adattamento al Cambiamento Climatico; MASE, 2023).

While in the European context, the response to the urgent and complex challenges of our time is pursued through community missions, strategies, and objectives (Directorate-General for Research and Innovation – European Commission, 2020), in the USA, the Inflation Reduction Act (Bistline et alii, 2023) represents the most significant investment in energy transition and climate resilience, alongside the Infrastructure Investment and Jobs Act (Bertrand, 2022), which supports green infrastructure invest-



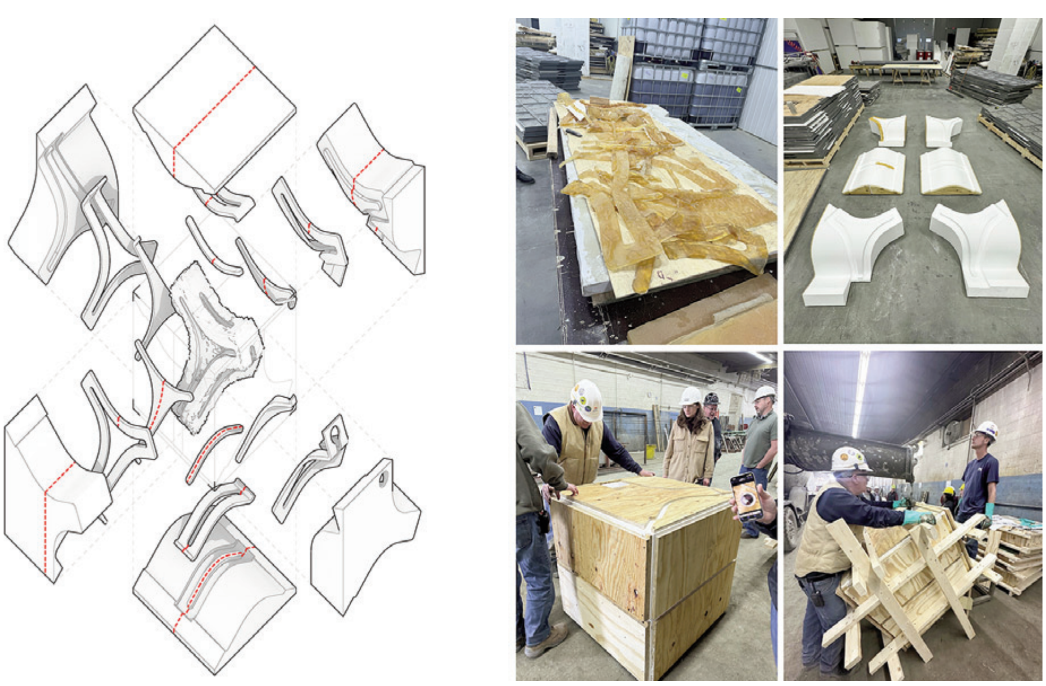


Fig. 10 | The installation of defence barriers and highlighting coastal habitats (credit: E. Beane and K. Napoli, RPI, 2024).

Fig. 11 | Prototypes of Intertidal Objects designed by Object Territories and RPI, located at Randall's Island, New York (credit: M. Carter, Object Territories, 2023).

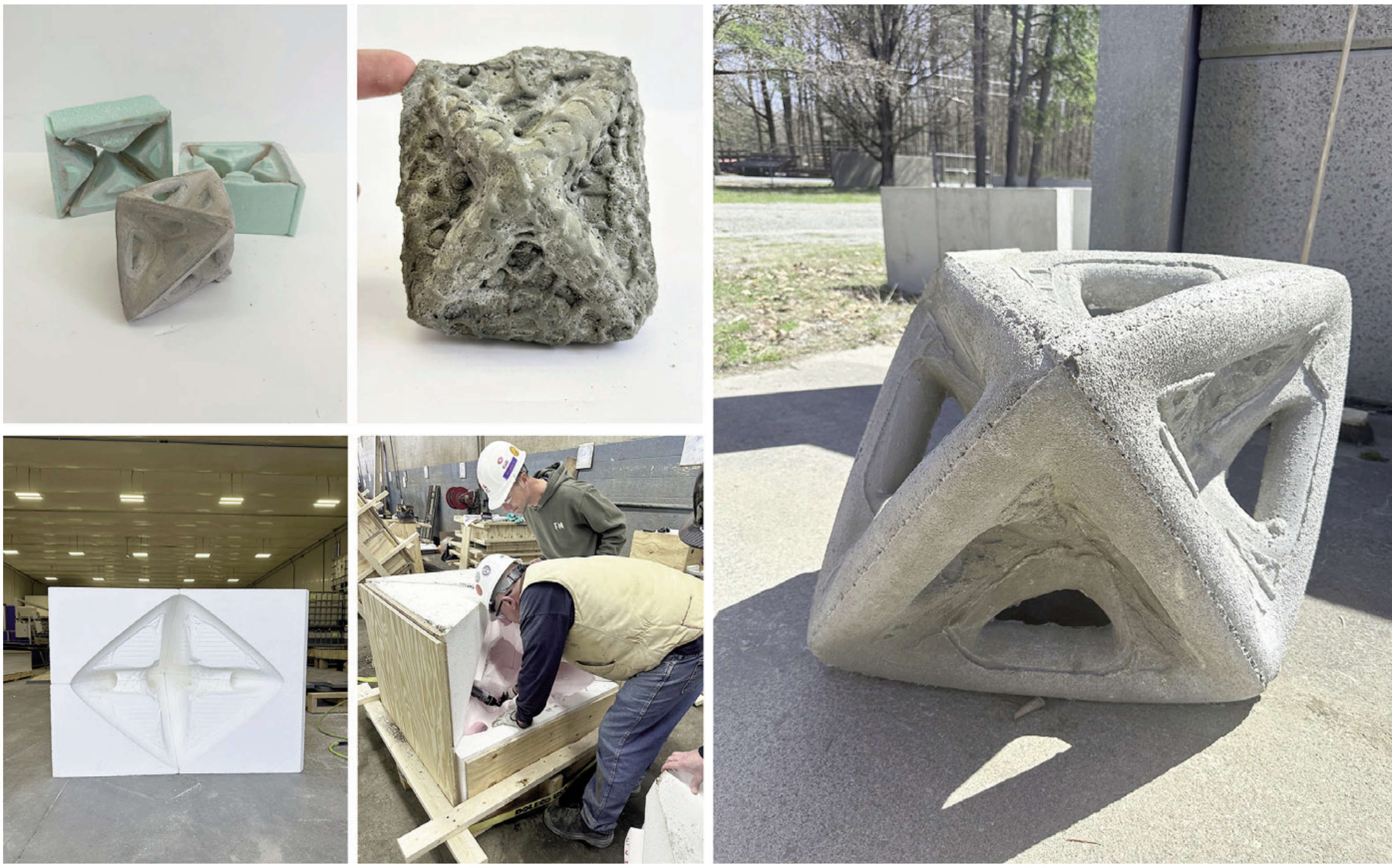
Fig. 12 | Technical drawing and photo of the mould formwork for the intertidal object designed by Object Territories and RPI, located at Randall's Island, New York (credit: E. Aprias and M. Morgan, RPI, 2024).

ments. At the local level, in New York City, climate challenges are addressed through PlaNYC (The City of New York, 2023), with a focus on extreme events such as floods and coastal storms (Braneon et alii, 2024).

State of the art | The field of investigation concerns coastal urban areas subject to flooding – projected up to 2100 – caused by the combined effects of progressive Sea Level Rise (SLR) and increasingly frequent flood events, both triggered by the rise in global average temperature (IPCC, 2023). The territorial context of reference, illustrated in the two case studies analysed, is, respectively, the Lazio coast, identified by ENEA as one of the 33 Italian areas most at risk of compromise by 2100 due to the SLR phenomenon (Antonioli et alii, 2017), and the port of New York, with the site of Governors Island subject to flooding because of tidal phenomena. Regarding the specificity of each area, the research results have delineated three urban resilience strategies against SLR and flooding: defence, adaptation and relocation / displacement, through the definition of a climate-proof and site-specific project toolkit that prioritises the use of Nature-Based Solutions (Mariano and Marino, 2019, 2022b).

The defence strategy refers to the need to protect the territory from the threats posed by climate change, where these represent a tangible risk to the population's safety, through hydraulic engineering and protective works (dikes, barriers, objects, etc.). The adaptation strategy pertains to the necessity of adapting the urban form to models and projections of change, considering the environmental context by implementing morphological reconfiguration actions that prioritise flexibility and diversity (Mariano et alii, 2021).

Meanwhile, the relocation / displacement strategy is the most radical and least explored, involving the displacement of the most vulnerable settlements to geomorphologically safer areas, in cases where the cost-benefit ratio of defence and adaptation measures is not deemed economically sustainable (Ryan, Vega-Barachowitz and Perkins-High, 2015). This strategy opens complex scenarios that require evaluating relocation modalities and new placement ar-



Figg. 13, 14 | Prototypes of Intertidal Objects designed by Object Territories and RPI and the mould formwork for the intertidal object (credit: E. Beane and K. Napoli, RPI, 2024); Intertidal Object designed by Object Territories and RPI, located at Randall's Island, New York (credit: M. Kokora, Object Territories, 2022).

Urban Zone	Value % of incidence on the total	Area m²
Expansions zones interested by high-risk	27.19%	114
Expansions zones interested by medium-risk	49.01%	206
Expansions zones interested by sea level rise in the SSP5-8.5 emissions scenario	2.27%	10
Expansions zones interested by hydraulic Risk in 2100 (Medium Risk + Sea level rise)	51.08%	245
Completion areas interested by high-risk	6.78%	6,242
Completion areas interested interested by medium-risk	35.09%	32,305
Completion areas interested by sea level rise in the SSP5-8.5 emissions scenario	2.02%	1,862
Completion areas interested by hydraulic Risk in 2100 (Medium Risk + Sea level rise)	37.11%	34,167
Private green conservations areas interested by high-risk	3.97%	10,465
Private green conservations areas interested by medium-risk	18.69%	49,235
Private green conservations areas interested sea level rise in the SSP5-8.5 emissions scenario	22.54%	59,377
Private green conservations areas interested by hydraulic Risk in 2100 (Medium Risk + Sea level rise)	41.23%	108,612
Total of urban planning areas interested by Hydraulic Risk in 2100 (Medium Risk + Sea level rise)	50.02%	388,039
Incidence ratio of the area of the urban planning areas in the district	26.79%	775,697 / 2,894,966
Reference parameters		
Urban district – Marina di Latina R9	100.00	2,894,966
Urban planning areas	100.00	775,697
Expansions zones	100.00	419,734
Completion areas	100.00	92,062
Private green conservations areas	100.00	263,482

Tab. 4 | Quanti-qualitative reading of incidence of hydraulic risk and sea level rise in the SSP5-8.5 emissions scenario on the urban planning areas – urban planning forecasts of the update of the detailed plan of 1999 (credit: F. Ianiri, 2024).

eas, while also addressing the issue of recovery and regeneration of areas freed from settlement pressure through large-scale environmental restoration projects.

Methodology | The methodology applied to the case studies, organised into operational phases, is aimed at understanding the complex dynamics related to hydraulic risk phenomena caused by flooding and SLR within an SSP5-8.5 emissions scenario in a specific target area. This allows for the contextualisation, definition, and subsequent implementation of the three macro-strategies of urban resilience-defence, adaptation, and relocation through the explicit identification of site-specific and climate-proof actions that can guide the resilient transition of coastal urban areas. Explication of the operational phases: 1) Definition of the cognitive framework of the hydraulic risk; 2) Analysis and qualitative-quantitative assessments; 3) Planning; 4) Design and experimentation; 5) Short, medium and long-term monitoring.

Focusing on the case study of Marina di Latina (LT), the first operational phase involves defining the cognitive framework for hydraulic risk in a specific portion of the territory identified as the target area. This is done through the preliminary creation of a risk map for SLR projected to the year 2100. To achieve this, elevation curves were extracted from the DTM (Digital Terrain Model) LiDAR with a resolution of 2 metres – while other supporting analyses were carried out using the DEM (Digital Elevation Model) file with a resolution of 10 metres – using QGIS 3.26.3 software. The elevation curve corresponding to cm 63 above sea level was then isolated, aligning with the projected coastal line for 2100 (Fig. 1), according to the emission scenario «[…] GHG SSP5-8.5 with projections of 0.20-0.29 m by 2050 and 0.63-1.01 m by 2100» (IPCC, 2023, p. 19). After determining the hydraulic risk from SLR, the risk factor associated with phenomena such as intense rainfall or river overflow was defined. Shapefiles were acquired from the risk and hazard maps included in the Flood Risk Management Plan (PGRA) produced by AUBAC (Autorità di Bacino Distrettuale dell'Appennino Centrale).

According to Article 6 of Italian Legislative Decree 49/2010 (Presidente della Repubblica Italiana, 2010) implementing Directive 2007/60/EC (European Parliament and Council of the European Union, 2007), the flood hazard and risk maps drawn up by AUBAC take into account the potential adverse consequences on the number of inhabitants potentially affected, the type of economic activities insisting in the area potentially affected, installations according to Directive 96/51/EC (Council of the European Union, 1996) that could cause accidental pollution in case of floods and protected areas potentially affected, areas where floods with high solid transport and debris flows may occur, and information on other significant sources of pollution.

To support the second operational phase of the qualitative-quantitative evaluation of these phenomena in the target area, the return period associated with the climatic event was analysed (Figg. 2-4), where the return period refers to the average time in which a given intensity value is equalled or exceeded at least once. Specifically, the authors referred to the return periods indicated in the Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA, 2021) report n. 353/2021, which highlights that for riverine floods, the return periods used in modelling within the Central Apennine District range between 30 and 50 years for the high-probability scenario, and between 100 and 200 years for the medium-probability scenario (Lastoria et alii, 2023).

The state of implementation of the planning instrument (PRG) was also assessed, and the relationship between systemic territorial components (environmental, settlement, and infrastructure systems) and climatic events associated with hydraulic risk. This analysis facilitated the identification of the planning instrument's weaknesses regarding responses to risks from flooding, intense rainfall, river overflow, and coastal erosion from SLR. It also enabled the identification of macro-strategies for urban resilience that move beyond the traditional sectoral approach in favour of an integrated approach to urban complexity, aligning with the ecosystem-based approach (Mariano and Marino, 2022a).

This approach is further developed through a toolkit of site-specific actions for hydraulic risk. The toolkit links project actions selected based on an analysis of best practices and case studies from similar contexts to systemic components relevant to the urban structure in the target area. In addition to integrating physical-territorial systems with macro-strategies for urban resilience, the toolkit allows for the clear definition of the benefits of actions, identification of key stakeholders, estimation of implementation costs, and establishment of timelines for action, which may be short, medium, or long-term.

The methodological framework, previously articulated by the authors in other research, innovates the procedural approach, based on a processual, iterative, and multi-scalar logic (Ricci and Poli, 2018), through the introduction of a parametric analysis of the incidence ratio between hydraulic risk phenomena and the systemic components of the target area, considering both the current state and future projections for the years 2053 and 2100. The comparison of results between future scenarios and the current state provides qualitative and quantitative evaluations to support policymakers in updating local planning instruments, reducing critical factors related to hydraulic risk identified during preliminary analysis. The methodology outlined above was applied to both the Port of New York and the Marina di Latina case study.

Case study of Marina di Latina | The experimentation of urban resilience macro-strategies was conducted in the target area of Marina di Latina (IT), identified as one of 30 high-hydraulic-risk areas along the Lazio coast. The risks are due to flooding, inundation, and SLR. This territory has unique geomorphological characteristics, primarily composed of silt, clay, sand, and ground depressions known as 'Tyrrhenian pools' (Fig. 5). According to Stanisci et alii (2001), the pools are typical depressions of flat areas subject to the surfacing of the groundwater table or abundant meteoric water supply, associated with clayey soils with slow drainage. They formed because the slight slope and dune ridges along the coast hindered the outflow of numerous watercourses fed by the Lepini and Ausoni mountains' springs.

Additionally, a study on the soils of the Province of Latina highlights the uniqueness of the target area, classifying it within the SR4 – Coastal plains with parent material defined by Quaternary marine deposits and SR9 – Sandy conglomeratic terraces, ancient 'red' dune category (Arnoldus-Huyzendveld, Perotto and Sarandrea, 2009). The study notes the presence of a rare soil type called Planosol in correspondence with the ancient dune in this coastal belt. However, the land reclamation processes of the early 1900s and spontaneous anthropisation from the mid-century onwards have significantly compromised the characteristic ecosystems of the Pontine Plain and the 'Tyrrhenian pools' surrounding the Marina di Latina target area.

This condition is also emphasised in a technical report by the Regional Parks Agency, aimed at identifying new protected areas in Lazio's coastal dune environment and analysing the coast from a geomorphological, vegetational, and faunal perspective, identifying coastal dune systems and assessing their degree of naturalness (Fattori et alii, 2010). The report highlights that the area where the target site is located, corresponding to physiographic unit number 4, between Capo d'Anzio and Capo Circeo, has the highest percentage of anthropised dunes on the Lazio coast. The area's fragility is further supported by the risk assessments emerging from the cognitive framework analysis.

During preliminary investigations, it was found that the new coastline projected for 2100, within the SSP5-8.5 emissions scenario, will affect 30.04% of the real estate[2] in the target area (Fig. 6). In areas demarcated as medium risk, corresponding to a 100-year return period, phenomena such as heavy rainfall and river overflow will impact 29.18% of existing buildings (Fig. 7), while in areas of high-risk, with a 30-year return period, these events will affect 9.61% of the total (Fig. 8). The risk analysis results must consider the overlap of various phenomena that could affect the target area, significantly altering the incidence and involvement of existing buildings. Indeed, in the SSP5-8.5 emissions scenario for 2100, if flooding and river overflow were to occur simultaneously or in close temporal windows, the number of affected buildings would increase substantially, reaching 56.09% of the total (Tab. 1; Fig. 9).

For a sub-limen territory, in transition, where the past, present, and future landscapes meet and intertwine» (Marino, 2023), and where the territory is 'suspended' due to risk, a potential loss, bringing an opportunity for physical and conceptual regeneration in an ecological key (Mariano and Marino, 2022b), the precariousness is exacerbated by the urban planning and development directives for the target area, which remain only partially implemented.

These directives foresee the completion of about 477.148 cubic metres out of a total of 636.190 cubic metres (Tab. 2) in the variant of the 1999 PPE (lit. Piano Particolareggiato Esecutivo) approved[3] in 1983. The analysis also highlighted another critical aspect in the target area's planning. The perimeter for the PPE implementation in the Marina di

Zone	Value % of incidence on the total	Area m²
Arable agricultural areas interest by high-risk	23.79%	453,703
Arable agricultural areas interest by medium-risk	47.64%	908,601
Arable agricultural areas interested by sea level rise in the SSP5-8.5 emissions scenario	0.81%	15,485
Arable agricultural areas interested by hydraulic Risk in 2100 (Medium Risk + Sea level rise)	48.45%	924,086
Open areas with sparse or no vegetation interested by high-risk	0.00	0
Open areas with sparse or no vegetation interested by medium-risk	0.00	0
Open areas with sparse or no vegetation interested by sea level rise in the SSP5-8.5 emissions scenario	54.76%	136,962
Open areas with sparse or no vegetation interested by hydraulic Risk in 2100 (Medium Risk + Sea level rise)	54.76%	136,926
Urbanized green areas interested by high-risk	0.72%	1,625
Urbanized green areas interested by medium-risk	8.20%	18,607
Urbanized green areas interested sea level rise in the SSP5-8.5 emissions scenario	28.89%	61,044
Urbanized green areas interested by hydraulic Risk in 2100 (Medium Risk + Sea level rise)	37.09%	79,651
Total of environmental system interested by Hydraulic Risk in 2100 (Medium Risk + Sea level rise)	47.84%	114,0663
Incidence ratio of the area of the environmental system in the district	82.37%	2,384,465 / 2,894,966
Reference parameters		
Urban district – Marina di Latina R9	100.00	2,894,966
Environmental System	100.00	2,384,465
Open areas with sparse or no vegetation	100.00	250,118
Arable agricultural areas	100.00	1,907,302
Urbanized green areas	100.00	227,045

Tab. 5 | Quanti-qualitative reading of territorial systems components affected by future flooding due to sea-level rise Projection: 63 cm by 2100 and interested by high and medium risk; reading the state of affairs of the environmental system (credit: F. Ianiri, 2024).

Latina district covers a land area of 2.894.966 sqm, while high and medium-hydraulic-risk areas extend over 1.469.301 sqm, occupying 50.74% of the total area, including zones within 300 metres of the shoreline. An additional factor to consider is the land area that will be affected by the advancing coastline by 2100. In the SSP5-8.5 scenario, the advancing coastline will affect 576.786 sqm, which, when added to the areas already identified as high and medium-hydraulic-risk zones, raises the incidence rate to 70.66% (Tab. 3).

According to the authors, the instrument's critical issues stem from the disconnect between its principles and guidelines for risk management, in identifying the territory's fragility, and in regulating and guiding its resilient development and its process of 'structured and lasting transition' (Litt, Businaro and Maragno, 2022). Latina's General Regulatory Plan (PRG), adopted in 1972 and still in force, belongs to the family of urban expansion plans (Campos Venuti and Oliva, 1993), developed in the second phase of Italian territorial development, a long phase that continued intensely for over thirty years until the late 1970s (Oliva, 2014).

These plans cannot respond to contemporary challenges, such as climate change in coastal urban areas. In this context, considering the fragility highlighted in the relationship between the existing fabric and climatic phenomena, the absence of a plan capable of addressing climate change challenges, and the urban planning provisions that could increase anthropogenic pressure and definitively break the precarious balance of the territory, these provisions play a fundamental role as potential vectors of urban regeneration. They can reintroduce landscape elements typical of the Pontine Agro, such as the 'Tyrrhenian pools', canals, dune systems with their flora and fauna, and, in general, all elements that make Marina di Latina resilient and unique, in line with the principles of the 2024 Nature Restoration Law (European Commission, 2024). For this reason, the authors decided to experiment with relocation and adaptation macro-strategies in the case study.

Case study of New York Harbour | The New York-New Jersey harbour estuary provides a case study where macro-strategies of resilience are systemically applied to address the phenomena of urban

Zone	Value % of incidence on the total	Area m²
T1 areas interest by high-risk	0.32%	514
T1 areas interest by medium-risk	3.56%	5,742
T1 areas interested by sea level rise in the SSP5-8.5 emissions scenario	30.89%	49,809
T1 areas interested by hydraulic Risk in 2100 (Medium Risk + Sea level rise)	34.46%	55,551
T2 areas interest by high-risk	7.94%	5,908
T2 areas interest by medium-risk	20.33%	15,127
T2 areas interested by sea level rise in the SSP5-8.5 emissions scenario	41.65%	30,983
T2 areas interested by hydraulic Risk in 2100 (Medium Risk + Sea level rise)	61.97%	46,100
T3 areas interest by high-risk	38.96%	7,906
T3 areas interest by medium-risk	91.98%	18,665
T3 areas interested by sea level rise in the SSP5-8.5 emissions scenario	0,00	0
T3 areas interested by hydraulic Risk in 2100 (Medium Risk + Sea level rise)	91.98%	18,665
T4 areas interest by high-risk	12.77%	73,313
T4 areas interest by medium-risk	37.49%	215,221
T4 areas interested by sea level rise in the SSP5-8.5 emissions scenario	20.34%	116,739
T4 areas interested by hydraulic Risk in 2100 (Medium Risk + Sea level rise)	57.83%	33,196
Total of morphological-settlement system interested by Hydraulic Risk in 2100 (Medium Risk + Sea level rise)	78.79%	452,276
Incidence ratio of the area of the morphological-settlement system in the district	28.67%	829,979 / 2,894,966
Reference parameters		
Urban district – Marina di Latina R9	100.00	2,894,966
Morphological- Settlement System	100.00	829,979
T1 - Spontaneous matrix fabric characterized by a herringbone road system, predominantly residential with a residential building typology and commercial functions located on the ground floors	100.00	161,266
T2 - Spontaneous matrix fabric characterized by a herringbone road system, mainly residential with a residential building typology	100.00	74,396
T3 - Spontaneous matrix fabric characterized by a herringbone road system, mainly residential with a residential typology of villa and building	100.00	20,293
T4 - Spontaneous matrix fabric characterized by an orthogonal road system, mainly residential with a detached residential typology	100.00	574,024

Tab. 6 | Quanti-qualitative reading of territorial systems components affected by future flooding due to sea-level rise Projection: 63 cm by 2100 and interested by high and medium risk; reading the state of affairs of the morphological-settlement system (credit: F. Ianiri, 2024).

coastal flooding and SLR[4]. The New York City Mayor's Office highlights the city's primary climate risks: extreme heat, storm surges, coastal storms, chronic tidal flooding, and extreme rainfall[5] (The City of New York, 2023). This extreme vulnerability of the territory was underscored after Hurricane Sandy, whose impact and trajectory through the New York Bight – the geographical angle formed by the New Jersey and Long Island coasts – caused a devastating surge in sea levels.

The Regional Plan Association (RPA, 2017) emphasises that governments must prioritise interventions in densely populated areas with high social and economic capital, necessitating both natural and engineering solutions to protect such regions from flooding and SLR[6]. Given financial limitations, lower-density areas will require a gradual retreat from the coast through zoning changes and publicly funded property acquisitions[7]. Additionally, rising insurance premiums will progressively make building in low-elevation areas more expensive (RPA, 2017).

The U.S. Army Corps of Engineers (2022), which has broad domestic jurisdiction over waterway navigation, flood protection systems, and environmental regulations, has proposed several options for the New York harbour, characterised by varying costs, timelines, and levels of protection. The most extreme scenario involves the installation of containment walls and water barriers – like Venice's MOSE barriers – to isolate New York Harbor from the Atlantic Ocean and Long Island Sound. The plan includes closing off Jamaica Bay and smaller waterways, as well as coastal protection along high-risk areas[8]. However, the financial and environmental costs associated with a tidal barrier system are significant, and such a system does not offer a long-term solution to SLR. This type of installation could affect salinity, water quality, sedimentation, and local ecologies. Moreover, the management by multiple agencies, funding from various sources, and the definition of who resides inside or outside the barrier raise significant political challenges (RPA, 2017).

In response to these heavy engineering proposals, New York designers have developed layered infrastructure projects that integrate public spaces, recreational activities, educational components, and habitats for flora and fauna. The following examples illustrate an ecosystem-based, cross-scalar ap-

Zone	Value % of incidence on the total	Area m² or length m
Roads interest by high-risk	5.56%	1,297 (m)
Roads interest by medium-risk	21.10%	4,921 (m)
Roads interested by sea level rise in the SSP5-8.5 emissions scenario	22.41%	5,227 (m)
Roads interested by hydraulic Risk in 2100 (Medium Risk + Sea level rise)	43.51%	10,148 (m)
Recreational and sports areas interest by high-risk	0.76%	1,762
Recreational and sports areas interest by medium-risk	8.14%	18,835
Recreational and sports areas interested by sea level rise in the SSP5-8.5 emissions scenario	26.06%	60,333
Recreational and sports areas interested by hydraulic Risk in 2100 (Medium Risk + Sea level rise)	34.20%	79,168
Industrial sports areas interest by high-risk	3.72%	2,757
Industrial areas interest by medium-risk	13.55%	10,054
Industrial areas interested by sea level rise in the SSP5-8.5 emissions scenario	6.94%	5,144
Industrial areas interested by hydraulic Risk in 2100 (Medium Risk + Sea level rise)	20.49%	15,198
Public car parks interest by high-risk	13.64%	17,532
Public car parks interest by medium-risk	2.37%	3,043
Public car parks interested by sea level rise in the SSP5-8.5 emissions scenario	16.44%	21,127
Public car parks interested by hydraulic Risk in 2100 (Medium Risk + Sea level rise)	18.81%	24,17
Total of service and infrastructure system (areas) interested by Hydraulic Risk in 2100 (Medium Risk + Sea level rise)	27.30%	118,536
Total of service and infrastructure system (linear) interested by Hydraulic Risk in 2100 (Medium Risk + Sea level rise)	43.51%	10,148
Incidence ratio of the area of the service and infrastructure system (areas) in the district	15.00%	434,179 / 2,894,966
Reference parameters		
Urban district – Marina di Latina R9	100.00	2,894,966
Service and Infrastructure System (areas)	100.00	434,179
Service and Infrastructure System (linear)	100.00	23,322 (m)
Roads evaluated according to linear parameter in metres	100.00	23,322 (m)
Recreational and sports areas	100.00	231,513
Industrial areas	100.00	74,174
Public car parks	100.00	128,492

Tab. 7 | Quanti-qualitative reading of territorial systems components affected by future flooding due to sea-level rise Projection: 63 cm by 2100 and interested by high and medium risk; reading the state of affairs of the services and infrastructure system (credit: F. Ianiri, 2024).

proach aimed at defining nature-based strategies across different design disciplines, from territorial to local scales and object-level design.

On the Water – Palisade Bay is a collaborative study by architects, engineers, planners, academics, and students that reimagines the upper quadrant of New York Harbor in response to SLR and storm-induced flooding[9]. The study questions the cost, effectiveness, and reliability of flood protection solutions based on heavy engineering, which have so far relied on seawalls, bulkheads, and levees, while neglecting the effectiveness of natural defences, such as marshes and wetlands, which can absorb tidal energy.

Furthermore, the jagged edges created by ship piers, which mitigated wave action and provided habitats, have disappeared following the relocation of shipping activities away from the Manhattan and Brooklyn docks (Nordenson, Seavitt and Yarinksy, 2008). The study proposes the creation of 'soft infrastructure', which combines an ecosystemic approach to storm protection.

The project consists of three main strategies: building islands and coral reefs in shallow waters to attenuate storm currents, creating a varied and porous shoreline with marshes and parks, and updating and integrating urban planning regulations to enhance climate resilience (Nordenson, Seavitt and Yarinksy, 2010). This work directly inspired the exhibition Rising Currents: Projects for New York's Waterfront at the Museum of Modern Art, which presented proposals for adaptive and 'soft' infrastructures in the harbour, raising public awareness of the risks and potential solutions (Bergdoll et alii, 2011; MoMA, 2010).

In 2014, the Federal Government launched the Rebuild by Design competition (González-Campaña et alii, 2023) for New York sites damaged after Hurricane Sandy. The SCAPE studio, led by Kate Orff, was awarded for the Living Breakwaters project, which involves installing ecological breakwaters in Raritan Bay, off the coast of Staten Island. These breakwaters disrupt wave action, slow water flow, and promote sedimentation along beaches. Viewing the project as part of a larger ecosystem, SCAPE defines the strategy as a 'layered approach', intertwining risk reduction, ecological enhancement, and community integration. State and federal funds provided $114 million for the construction of nine break-

Components system	Goals	Site specific actions	Urban resilient macro strategy		
Environmental system	Reconnection of the existing ecological network to restore biodiversity, enhancement of reclamation channels, and high-natural-value areas	Creation of green corridors through the completion of existing tree lines	a	b	c
		Creation of new green corridors through the planting of new tree lines	a	b	c
		Establishment of local and urban parks within the free areas present in the fabric	a	b	c
	Adaptation interventions in flood and inundation risk areas	Expansion of reclamation channels to channel floodwaters	a	b	c
		Establishment of river parks	a	b	c
		Natural accumulation of sand in dunes and beaches	a	b	c
	Soft protection interventions in flood and inundation risk areas with subsequent transformation into a living shoreline	Creation of elevated paths near dunes and new coastal areas	a	b	c
		Creation of paths integrated into the terrain slopes near existing channels	a	b	c
		Creation of gently sloping natural embankments on portions of the shoreline subject to flood and inundation events	a	b	c
		Creation of gently sloping natural embankments near channels	a	b	c
Morphological Settlement System	Implementation of territorial reorganisation strategies to reaggregate the existing fabric	Relocation of residents to areas with lower risk	a	b	c
		Creation of functional mixité	a	b	c
		Construction of new buildings on currently agricultural land, including the expansion and revision of the urban complex perimeter	a	b	c
		Completion of urban voids	a	b	c
		Demolition or conversion of existing buildings	a	b	c
		Preparation and creation of floodable areas	a	b	c
	Creation of new centralities for the definition of social gathering places	Creation of new pedestrian squares and temporary squares	a	b	c
		Creation of floodable squares	a	b	c
Services and infrastructures system	Strengthening of mobility infrastructure to define and improve vehicular traffic flows, as well as implementing strategies for soft mobility planning	Integration of ecological transport into existing infrastructure services	a	b	c
		Creation of new local-level mobility infrastructure	a	b	c
		Expansion of existing road sections	a	b	c
		Expansion and restructuring of existing connecting bridges	a	b	c
	Implementation and enhancement of local and urban public services	Creation of new resilient tourist and hospitality services	a	b	c
		Creation of equipped green spaces within free areas	a	b	c
		Creation of areas designated for vehicular parking, prioritising the electric vehicles' parking	a	b	c
		Increase in the supply of various services within existing and newly developed areas	a	b	c

Tab. 8 | Toolkit of site-specific actions applied to Target Area Marina di Latina, also reading the relationship between territories components system and challenges; the letters refer to the 3 macro-strategies of a) adaptation, b) defence, and c) relocation (credit: F. Ianiri, 2024).

Site specific action	Parameter	Evaluation		Measurement (m², length, cost, time)
Action	Reduction of vulnerability	1-2	Minimal vulnerability reduction	
		3-4	Moderate vulnerability reduction	
		5-6	Significant vulnerability reduction	
		7-8	Almost total vulnerability reduction	
	Reduction of Climate Risk	1-2	Minimal risk reduction	
		3-4	Moderate risk reduction	
		5-6	Significant risk reduction	
		7-8	Almost total risk reduction	
	Protection of Critical Infrastructure	1-2	Minimal protection	
		3-4	Moderate protection	
		5-6	Significant protection	
		7-8	Almost total protection	
	Safeguarding Natural Resources	1-2	Limited protection of natural resources	
		3-4	Moderate protection of resources	
		5-6	Good protection of resources	
		7-8	Excellent protection of resources	
	Economic Sustainability	1-2	Poor economic sustainability	
		3-4	Moderate economic sustainability	
		5-6	Good economic sustainability	
		7-8	Excellent economic sustainability	
	Community Engagement	1-2	Minimal engagement	
		3-4	Moderate engagement	
		5-6	Significant engagement	
		7-8	Very high engagement	
	Environmental Impact	-5 to -3	Strongly negative environmental impact	
		-2 to -1	Slightly negative environmental impact	
		0	No impact	
		1 to 2	Slightly positive environmental impact	
		3 to 5	Strongly positive environmental impact	
	Social Equity	1-2	Limited benefits for the population	
		3-4	Moderate benefits, but not evenly distributed	
		5-6	Good distribution of benefits	
		7-8	Benefits evenly distributed among all population groups	
	Cost-effectiveness (cost / benefit ratio)	1-2	Low cost-effectiveness	
		3-4	Moderate cost-effectiveness	
		5-6	Good cost-effectiveness	
		7-8	Excellent cost-effectiveness	
	Implementation Time (time required to implement the action)	1-2	Long duration (> 5 years)	
		3-4	Moderate duration (3-5 years)	
		5-6	Short duration (1-3 years)	
		7-8	Very short duration (< 1 year)	
	Action Flexibility	1-2	Low flexibility, difficult to adapt	
		3-4	Moderate flexibility	
		5-6	Good flexibility	
		7-8	High flexibility, easily, adaptable	
	Ongoing Stakeholder Involvement	1-2	Minimal or absent involvement	
		3-4	Moderate involvement	
		5-6	Good level of involvement	
		7-8	Continuous and active involvement	
Evaluation results	**Maximum value**	**93**		
	Real value		–	

Tab. 9 | Quantitative-qualitative evaluation on a parametric basis of project actions for adaptation to climate change and reduction of hydraulic risk (credit: F. Ianiri, 2024).

waters, completed in 2024 (New York State, n.d.).

The crests of the breakwaters extend toward the ocean to increase structural complexity and host intertidal habitats for fish, crustaceans, and molluscs. The sedimentation zone onshore provides habitats for clams, seagrasses, and generates salt marshes, while the terrestrial portion offers protected habitats for seals and birds (Orff, 2016; Fig. 10). The installation uses a combination of rocks, gabions, and prefabricated ecological armour units, as well as units to form 'tidal pools'. Citizen engagement will be facilitated through beach restoration and the creation of educational centres along the coast, alongside the Billion Oyster Project (2019), which aims to reintroduce a billion oysters into the harbour by 2035[10] (Orff, 2016). As Orff (cit. in Klinenberg, 2021, p. 18) notes, «We've spent the past one hundred years dredging out everything for shipping and hardening the edges. Now we have a different climate, and we need a different approach».

In this design context, intertidal objects enrich the cross-scalar and multidisciplinary framework with the aim of developing living shorelines. These ecological installations promote the growth of native species and provide protection against erosion, constituting an essential component of a 'layered' shoreline. This approach integrates various elements to ensure urban resilience, combining ecological and engineering components. Ecologically sustainable armour units and containment panels not only contribute to coastal fortification but also enhance adaptability, considering that many existing investments cannot simply be abandoned. It is crucial to integrate existing infrastructure and projects into new adaptation and resilience strategies.

Initiated as research by Object Territories, a design studio based in New York and Hong Kong, this project was later developed as a research initiative at the Rensselaer Polytechnic Institute (RPI), with consultancy from the CASE (Center for Architecture, Science & Ecology) at RPI, afterNature based in Hong Kong, and the Fort Miller Group of New York[11]. The group established design parameters, such as ballast factor, porosity, surface texture typology, and the ability to aggregate and interlock with existing rocks or other fabricated units (Figg. 11-13). When placed in intertidal waters, these three-dimensional concrete units can create microenvironments for aquatic creatures and algae[12] (Fig. 14). As installations, they represent only one part of a layered approach necessary for building a resilient coastline. These projects demonstrate that innovative design can offer effective strategies for mitigating the effects of climate change in urban coastal areas, planning for SLR adaptation, and restoring natural ecologies.

Results | Thanks to the innovative methodological process tested in the Marina di Latina case study, it was possible to conduct a dual qualitative-quantitative analysis of the hydraulic risk's impact on the urban areas planned by the PPE and the systemic territorial components.

In the first instance, the analysis revealed that 49.01% of the expansion areas identified by the plan, which are still unimplemented for residential purposes, are subject to medium risk. Over a 100-year return period, the risk impact on the urban zones amounts to 50.02%, affecting half of the areas under planning (Tab. 4). These findings highlight the need for a structured and integrated revision process of the PPE for the R9 District Marina di Latina and its provisions, with the prerequisite of thoroughly understanding the territory and its relationship with hydraulic risk, as well as the results of the qualitative-quantitative analysis. On the other hand, the results of the analysis on the relationship between risk and systemic territorial components indicate that, under the SSP5-8.5 scenario, the environmental system will be impacted by 82.37% (Tab. 5), the morphological settlement system by 78.79% (Tab. 6), and the service and infrastructure systems by 27.30% for areal components and 43.51% for linear components (Tab. 7).

The qualitative-quantitative analysis results provided a critical framework that guided the definition of strategies and project actions, categorised through a climate change adaptation toolkit (Mariano and Marino, 2022a; Tab. 8) and assessed for their risk reduction effectiveness via a parametric matrix (Tab. 9). Each project action was associated not only with a macro-strategy for urban resilience and the climate resilience objective to be achieved but also explicitly aligned with qualitative-quantitative parameters, enabling an evaluation of the project's impact on the target area.

In addition, special attention was paid to the use of a nature-based ecosystem approach. NbS (Nature-based Solutions), which harness nature and the power of healthy ecosystems to protect people, optimise infrastructure and safeguard a stable, biodiversity-rich future, were integrated into the design choices (EEA, 2021). In fact, analysing the climate change adaptation toolkit drawn up for the Marina di Latina case study, among the NbSs selected to contribute to the pursuit of the objectives, there are actions such as the creation and restoration of green corridors, the establishment of river parks, and the restoration of the dune component aimed at reducing the effects of coastal erosion.

The results from the project on the Marina di Latina target area demonstrate how integrated strategies for adaptation, relocation, and 'soft' defence (Al, 2018) can be implemented to achieve the goal of transition and climate resilience in the target area.

Meanwhile, the experimentation with intertidal objects in the Port of New York case study began with a pilot project involving the installation of units designed by Object Territories and RPI, placed at Randall's Island, New York. A new installation is scheduled to be placed on Governors Island, supported by the Trust for Governors Island as part of the Climate Solutions Challenge (Governors Island, 2024), pending approval from the New York State Department of Environmental Conservation. The iterative installation did not use low-pH concrete, while FMG will produce components for the second installation using both standard and low-pH concrete mixtures to evaluate potential differences in the adaptation process. The scientific team will monitor the sites over several annual cycles, documenting the development and success of the habitat. In terms of effectiveness, the first installation has already shown rapid results[13]. It took only a few weeks for marine plants to begin colonising the objects, thanks to the nutrient-rich brackish waters at the confluence of the Harbour and East River. These initial results present optimistic scenarios, although the authors are aware that scientifically valid conclusions will require further prolonged observation.

Conclusions | The case studies presented highlight the innovative nature of the applied methodology, which guides the planning processes of coastal urban areas and enhances resilience to the effects of climate change. The multidisciplinary, integrated, and interscalar approach adopted enables a comprehensive and articulated response to emerging challenges, providing an in-depth understanding of both local and global dynamics.

The qualitative-quantitative analysis of the systemic territorial components, as well as the legal and factual state of the urban context, allows for the development of site-specific solutions that address both immediate needs and long-term sustainable and adaptive transitions (Ricci and Mariano, 2022). Additionally, the methodological models derived from the case studies are transferable and replicable in similar contexts. The limitations of the contribution can be found in the further possibility of integrating new technologies and approaches into the method, such as the correlation between SLR and land subsidence, and the understanding of the dynamics related to the phenomenon of saline wedge rise in the soil caused by SLR, which could further improve the effectiveness of urban resilience strategies, offering better responses to climate challenges.

Future evaluations of the impact that intertidal objects will have in creating micro-environments for aquatic creatures while defending the coast, which is currently being monitored, and making it resilient will further clarify the project's benefits.

Design experiments represent opportunities to form, improve, and expand the knowledge base regarding the effects of design interventions, and to define parameters and indices for the parametric evaluation of projects prior to their implementation. This work is part of an interscalar pathway, ranging from the formulation of macro-strategies for urban resilience to the concrete realisation of project actions, emphasising the importance of a systemic, interscalar, and interdisciplinary approach in urban planning. It also promotes a continuous dialogue between research and practice to achieve long-term climate resilience and sustainability goals.

Notes

1) In recent years, these activities have been conducted by the group coordinated by C. Mariano within the framework of the national research project PNR (lit. National Research Programme) 'Sustainable Transitions for Adaptation and Urban Regeneration Towards a Climate-Proof Urban Planning' (PI Carmela Mariano, 2022); in the University Research projects 'Urban Regeneration Strategies for Climate-Proof Territories – Tools and Methods for Vulnerability Assessment and Resilience Tactics Identification in Coastal Urban Areas Subject to Sea Level Rise' (PI Carmela Mariano, 2020) and 'Climate-Proof Planning and Regeneration Strategies for Adaptation to Sea Level Rise Phenomena – Experimentation and Innovation in Local Urban Planning in Risk Areas of Lazio' (PI Carmela Mariano, 2021); and further explored through research activities in the PhD programme in Planning, Design, and Technology of Architecture (Department PDTA 'Sapienza'). Within the international scientific cluster 'Medways – The Mediterranean Ways' coordinated by Prof. Mosè Ricci (University of Trento), in collaboration with the National Academy of Sciences, with the research project 'Landscapes of the SubLimen – Itinerary Through the 'Suspended' Territories of the Adriatic Coast' curated by C. Mariano and M. Marino (2019-2022); and in the H2020 Marie Curie research project 'SOS Climate Waterfront – Linking Research and Innovation on Waterfront through Technology for Excellence of Resilience to Face Climate Change', Interdepartmental Focus Center, 'Sapienza'.

2) The data correspond to the volumes present in the 2014 Regional Technical Map, scale 1:5,000, produced by the Province of Latina.

3) The data related to the volumes present in the R9 – Marina di Latina area was obtained from the 2014 census conducted by the Municipality of Latina.

4) Hurricane Irene in 2011 and Hurricane Sandy in 2012 brought the threat of storm surge to the forefront of resilience discussions in the New York metropolitan area. In addition to these extreme events, sea level rise remains a long-term threat to the area, with some scientists, such as John Englander, suggesting a sea level rise of up to 2.5-3 meters by the end of this century, with corresponding risks of more intense storm surges, flooding, and erosion (Englander, 2021).

5) Although classified as a Category 1 storm based on wind speed (NHC, 2021), Hurricane Sandy ranks fifth in terms of damage, with an estimated cost of $88.5 billion, according to the National Oceanic and Atmospheric Administration (NOAA, 2024). According to a report by the U.S. Department of the Interior and the United States Geological Survey, the maximum tide height during Sandy reached 5.15 meters above the North American Vertical Datum of 1988 – NAVD 88 (Schubert et alii, 2015). Current sea level rise projections from the New York City Panel on Climate Change (NPCC), relative to a 2000-2014 baseline, range from 0.38 m to 1.91 m by 2100. Considering a possible nonlinear acceleration of glacial mass loss, especially in the latter half of the century, the NPCC's rapid ice melt scenario (ARIM) projects a physically plausible upper limit of 2.90 m for New York by 2100 (Gornitz et alii, 2020).

6) The Regional Plan Association is an independent planning organisation that produces strategic reports for the tri-state region, as New York, New Jersey, and Connecticut are part of the New York metropolitan area. The RPA aims to overcome the political fragmentation of the three state governments and numerous local governments by proposing regional-scale recommendations. The RPA produced its first report in 1929 and its fourth (and most recent) in 2017.

7) The city's PlaNYC document suggests the need to acquire properties in low-lying areas, specifically targeting homeowners, but indicates that the city will seek state and federal funds to purchase the homes, without guaranteeing the reliability of such funding (The City of New York, 2023).

8) Acknowledging the project's limitations, they explicitly state that all alternative plans will have benefits for no more than 50 years. The planning horizon, which is a 100-year period to account for the effects of relative sea level change, is defined as 2016-2115 (2016 is the start of the study).

9) It is important to note that this research project was conducted before Hurricanes Irene and Sandy struck the New York area. Tropical cyclones rarely make landfall in this region compared to the southeastern United States.

10) Oyster restoration remains a significant component as they reinforce coral reefs and purify the water. The Oyster Habitat Restoration Monitoring and Assessment Handbook notes that oysters can be established using various methods: engineered concrete domes, such as 'reef balls', metal containers, such as gabion baskets, or other strategies with bags (Baggett et alii, 2014).

11) The work is based on ongoing pilot installations by Object Territories and afterNature in Victoria Harbour, sponsored by the Hong Kong government.

12) A variety of barnacles, mussels, and other sessile organisms thrive in the intertidal waters of the New York Harbor estuary. Fish species include the American eel, striped bass, Atlantic silverside, and oyster toadfish, among others. Pacific crabs, isopods, and oyster borers represent some of the mobile invertebrate species in this habitat (Billion Oyster Project, 2019).

13) One of the commercially recognised suppliers of coastal protection units has claimed that a 'bio-enhancing' mix (commonly understood as low pH) better supports biodiversity on the surface (Keegan, 2020). Other studies, which tested concrete in waters of the UK and Singapore, suggested that pH level does not have a discernible effect on species' hospitality and that the high alkalinity of fresh concrete stabilises quickly (Hsiung et alii, 2020).

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