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Eco-creative nature-based solutions to transform urban coastlines, local coastal communities and enhance biodiversity through the lens of scientific and Indigenous knowledge

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Abstract

Increasing anthropogenic pressure on the sea and alteration of coastscapes challenge the functioning of marine ecosystems and long-term reliance on blue economies, especially for developing southern economies. The structural hardening of shores can result in ecological disruptions, with cascading effects on the wellbeing and livelihoods of marginalised groups who depend on marine resources. Mitigation, adaptation and rehabilitation options for coastal developments should include innovative, socially responsible solutions to be used to modify shorelines and ensure long-term functionality of metropolitan coastal ecosystems. Nature-based innovations are being developed to improve surrogacy for natural marine ecosystems. The co-creation of nature-based structures, entailing partnerships between scientists and a local rural community is currently being considered in South Africa and we present this regional case study as a transdisciplinary framework for research in nature-based, ecological engineering of coastal systems. Novel transdisciplinary approaches include ecomusicological interventions, where traditional cultural expressions (TCEs) create opportunities for transgressive pedagogy. This step aims to ensure that the knowledge gathered through nature-based scientific research remains a part of community developed Indigenous knowledge systems. The merging of innovative, eco-creative approaches and TCEs has the potential to sustainably and ethically improve the functioning and diversity of coastal urban habitats. This review tackles the potential of transdisciplinary settings to transform urban coastlines using "low-tech" engineering and Indigenous eco-creative innovations to pedagogy, to benefit the people and biological communities as well as reduce social and gender inequalities.

Impact statement

This transdisciplinary review has the potential to shift the classic paradigms of perceiving and applying ecological engineering in coastal ecosystems. This impact is primarily driven by the centrality of Indigenous knowledge, people and local communities in the co-creation of nature-based solutions. Through an equitable and fair process, the active engagement by local communities in eco-creative innovations and transformative pedagogies will lead to meaningful benefits for people and the biological coastal communities.

The main objective of this review is to summarise diversified evidence, identify gaps in knowledge and extract concepts from multiple disciplines to offer a pioneering model and change of narratives for research on nature-based ecological engineering approaches in the coastal realm. This perspective involves and relates to multiple topics or fields, more specifically marine nature-based solutions in urban coastal habitats, Indigenous knowledge, musicology (ecomusicology) and transgressive pedagogies. An extensive review of literature was therefore required to ensure an inclusive and exhaustive synthesis and assessment of the information available on this transdisciplinary objective. To explicitly achieve this, multiple strings of keywords, closely related to the different topics/disciplines, were entered into search engines (refer to Table 1 for keyword strings searched). Each keyword string, was assessed using the standard repositories and bibliographic database tools, Elsevier Scopus (www.scopus.com) and Google Scholar (www.scholar.google.com) between 1960 and 2022. Web of Science (WoS) was initially also used, however, WoS generated the fewest records and those largely overlapped with the results

Table 1. Assessments of the search strings outputs based on the main disciplines of the review using Scopus and Google Scholar, filtering keywords in titles and abstracts

	Scopus		Google Scholar	
Keyword strings	Number of articles returned	Title and abstract level screening	Number of articles returned	Title and abstract level screening
Discipline 1: Marine nature-based solutions in urban coastal habitats				
"Marine" + "ecological engineering"	1,149	218	1,000	87
"Marine" + "nature based solutions"	395	70	1,000	113
"Living shorelines" + "restoration"	89	48	1,000	80
"Coastal artificial structures" + "ecological modifications"	25	20	1,000	177
Discipline 2: The use of Indigenous knowledge and nature-based solutions in communities				
"Marine" + "Indigenous knowledge"	478	75	1,000	76
"Indigenous knowledge" + "nature based solutions"	46	20	1,000	40
"Nature based solutions" + "Indigenous communities"	66	25	1,000	49
"Nature based innovations" + "Indigenous knowledge"	30	14	1,000	27
Discipline 3: Ecomusicology and traditional cultural expressions in communities				
"Ecomusicology"	52	37	1,000	75
"Music" + "traditional cultural expressions" + "communities"	42	28	1,000	19
"Soundscapes" + "ecology" + "culture"	20	15	1,000	14
"Music" + "sound" + "culture" + "sustainability"	11	9	1,000	32
Discipline 4: Transgressive Indigenous pedagogies				
"Transgressive" + "pedagogies"	72	19	1,000	50
"Indigenous" + "pedagogies" + "music"	30	20	1,000	65
"Creative" + "ecological" + "pedagogies"	39	20	1,000	27
"Arts-based" + "pedagogies" + "action research"	47	29	1,000	58

Note: Timing of acquisition: 1–25/11/2022.

obtained from the searches from the other engines. The search engine WoS, was therefore excluded. The number of articles returned from each search was screened and selected based on the relevant keywords (Table 1) being present in the title and abstract. For Google Scholar, the maximum amount of scholarly literature returned did not exceed 1,000, therefore, for each field of study/discipline and search, a maximum of 1,000 peer-reviewed articles were reviewed using this search engine. From the literature screened, according to the procedure described above, references and in-text citations were included in the manuscript where applicable (see Supplementary Materials A and B for full outputs of search strings).

Overview

Ecological engineering in the built coastal environment

With continued societal and economic pressures on our coast and oceans, the impact on natural coastlines from urbanisation through development and coastal defence cannot be reversed, especially with increasing challenges from climate change affecting shorelines worldwide (e.g., Costanza et al., 1997; Todd et al., 2019). Due to trade and maritime transport (Todd et al., 2019), humans increasingly migrate towards coastlines (Creel, 2003; McGranahan et al., 2007), with the population density within 100 km of the sea being almost three times higher than the global average (Small and Nicholls, 2003; Duarte et al., 2008). An example of the sharp growth in coastal urbanisation is given by the rapid increase in infrastructures being built in coastal areas which range from 3.7% (merchant ships requiring harbour space) to 28.3% a year (offshore wind energy; Duarte et al., 2013). In addition, the escalating atmospheric concentrations of greenhouse gases linked to human activities have resulted in the rising of the Earth's average temperatures which in turn has increased the world's coastal sea surface temperatures by approximately 1°C (IPCC, 2019). As a result, global mean sea levels have risen over the last 10 years at a rate of almost 4 mm per year and extreme weather events are increasing in frequency and intensity (Doney et al., 2012; IPCC, 2014, 2019). To counteract the effects of climate change threats and to protect people and property from inundation and erosion (i.e., shoreline stabilisation) in these ever expanding coastal urban cities, multifaceted coastal defences or armouring (i.e., "ocean sprawl"; Duarte et al., 2013), such as seawalls, breakwaters, revetments, bulkheads, pontoons, jetties and slipways, are constructed (Chapman and Bulleri, 2003; Moschella et al., 2005; Bulleri and Chapman, 2010; Dafforn et al., 2015).

The current worldwide pressures on the sea and fundamental structural alteration of coastscapes pose serious challenges to the sustainable functioning of coastal ecosystems and the long-term reliance on blue economies. This is particularly relevant to South Africa and the 2014 Operation Phakisa (Sotho expression for "hurry up"), a governmental socio-economic plan to fast-track the "blue economy" of ocean development across a number of sectors (https://www.operationphakisa.gov.za/; Vreÿ, 2019; Oceans Economy in the Eastern Cape and South Africa, 2020). Yet, limited country-specific information on the links between coastal urban development and ecosystem functioning is available. The start of the new decade, and specifically the recent worldwide state of COVID-19-related disaster, have also highlighted how important safeguarding natural biodiversity is to fuel the resilient recovery of natural ecosystems (Coll, 2020). It has long been predicted that by increasing the stress on natural systems through pollution and/or habitat destruction, marine biodiversity will change, with repercussions for the ecosystem functioning (Worm et al., 2006). High species richness and diversity can enhance ecosystem productivity and stability (Stachowicz et al., 2007), while a decline in biodiversity may alter ecosystem functioning with a consequent loss of services (Worm et al., 2006; reviewed in Gamfeldt et al., 2015; Jungblut et al., 2020). As such, a more diverse community is likely to respond to anthropogenic stressors without compromising (or at least, not fully) the functions and services of a system. Yet, the structural modification and hardening of the shores often result in significant direct and indirect ecological impacts on natural coastscapes that cannot be reversed (Bulleri and Chapman, 2010; Todd et al., 2019). These impacts too frequently biologically translate into habitat degradation, reduced resilience to natural disasters, loss of biodiversity, accelerating species extinction and the spread of invaders (e.g., McKinney and Lockwood, 1999; Chapman and Bulleri, 2003; Arkema et al., 2013; Airoldi et al., 2015; Dafforn et al., 2015; Mayer-Pinto et al., 2018).

Furthermore, concerns about the sustainable functioning of marine ecosystems and the long-term reliance on blue economies may arise (Claudet et al., 2020). Direct ecological impacts from coastal armouring, especially made from concrete and granite to replace natural habitats, for example, rocky shores (Firth et al., 2014; Dyson and Yocom, 2015; Todd et al., 2019) are numerous. These include habitat loss, fragmentation and degradation (Peterson and Lowe, 2009; Bulleri and Chapman, 2010; Bishop et al., 2017; Heery et al., 2017; Airoldi et al., 2021), reduction in microbenthic diversity of invertebrate community integrity (Peterson et al., 2001; Chapman, 2003; King et al., 2005; Bilkovic et al., 2006; Seitz et al., 2006; Bilkovic and Roggero, 2008; Morley et al., 2012), alteration to the physical (Bozek and Burdick, 2005; Heery et al., 2017) and chemical (Heery et al., 2017) properties and processes, increase in marine pollution associated with sewage and urban runoff (Trombulak and Frissell, 2000; Cornelissen et al., 2008; Todd et al., 2019), change in nutrient availability (e.g., Bishop et al., 2017). Indirect ecological impacts from coastal artificial structures include altering species composition, abundance and predator–prey interactions (Bishop et al., 2017; Heery et al., 2017), decreasing the reproductive output of species (Moreira et al., 2006), altering trophic transfer (Airoldi et al., 2010; Moss, 2017). Alternatively, limited studies have shown that artificial structures could have ecological benefits such as increasing the abundance of subtidal epibiota, their fitness and overall diversity in shallow urbanised coastal areas (Page et al., 1999; Burke et al., 2005; Connell and Glasby, 1999; Davis et al., 2006; Currin et al., 2010; Feary et al., 2011) due to the generally more benign, sheltered, and retentive nature of such environments. As such, marine biodiversity will change, with repercussions for the ecosystem functioning (Worm et al., 2006). While differences in biodiversity between natural and anthropogenically-modified habitats have been reported, mostly highlighting the common thread of an increase in invasive species (Perkol-Finkel et al., 2012; Firth et al., 2016), the effects of urbanisation on the functionality of these systems have received less attention. Recent research efforts within intertidal communities have shown that the functional properties and biological interactions also suffer from the structural alterations to the natural ecosystems (Ferrario et al., 2016).

Evidence of the (economic) impacts of coastal development and associated activities have been reported for coastline adaptation/transformation to, for example, sea level rise (Williams et al., 2013; Reguero et al., 2014; Rizvi et al., 2015; Hummel et al., 2021; Hynes et al., 2022). The consequences for marine biodiversity and food security have, however, been more challenging to explicitly translate (but see Carlton, 1996 for an example of ship ballast mediated bio-invasions and impacts on fisheries and Mead et al., 2011 for ports as major pathways for the introduction of invasive species). New paradigms, integrating a dual approach that addresses both the safe development of human societies and the integrity of biodiversity, are hence clearly needed (Steffen et al., 2015). This is especially true for the vulnerable coastal regions of the world, Africa included, where the effects of climate-change and urbanisation are likely to be severe (Nicholls and Cazenave, 2010). The need for a blue economy to incorporate not only economic perspectives but also ecological, socio-cultural and institutional objectives is sorely needed to enable a more holistic approach that includes social equity and environmental sustainability (Okafor-Yarwood et al., 2020). Mitigation, adaptation, rehabilitation and restoration options for degraded or altered habitats, either through active ecological engineered interventions or managed realignment (sensu French, 2006) should include innovative, socially responsible practices, as well as solutions that speak to local conditions and local communities as well as broad latitudinal gradients. Finally, such solutions should be used to allow urban shorelines to enhance and/or recover as many biological processes as possible and ensure a long-term, effective functionality of coastal ecosystems (Mayer-Pinto et al., 2019).

Rising research on ecological engineering is tackling how improvements on the design of artificial structures and increase in complexity can mitigate the effects of urbanisation and climate change by considering species' current home ranges; species' adaptive potential to endure and function under current and predicted environmental and ecological conditions; and interactions between global and local stressors to sustainably enhance and restore natural biodiversity (Mayer-Pinto et al., 2017; Strain et al., 2018; Mayer-Pinto et al., 2019). Heterogeneity of otherwise homogenous coastal armouring is key to biodiversity enhancement and examples of coastal ecological engineering include either additive or subtractive processes (Chapman and Underwood, 2011). Additive processes comprise the use of elements such as concrete tiles and flowerpots to attach to seawalls (e.g., Chapman and Underwood, 2011; Dafforn et al., 2015). Subtractive processes include the drilling of pits and/or grooves; alteration of surface texture/roughness/porosity/slope; fingerprinting of the natural substrate; creation of pools of different sizes and potential microhabitats that favour ecological improvement through, for example, water retention and fine scale flow (Chapman and Blockley, 2009; Chapman and Underwood, 2011; Perkol-Finkel et al., 2012; Firth et al., 2013, 2014, 2016; Evans et al., 2021). Ecological engineering options have also recently been compiled to provide informed guidance to a range of stakeholders for interventions on hard artificial infrastructures (O'Shaughnessy et al., 2020). These innovative approaches, that is, "hard ecological engineering", however, still mostly operates on the use of replacement habitats made of barren substrates (e.g., concrete, metal and stone; Komyakova et al., 2019) for nature to restore. The greenest and latest innovative approaches include hybrid ecological engineering, which combines ecologically enhanced hard structures with ecosystem engineers to enhance coastal biodiversity and resilience of coastal communities (Sutton-Grier et al., 2015; Firth et al., 2016; Bishop et al., 2017; Strain et al., 2018, 2020). Ecosystem engineering species such as seagrass (Bos et al., 2007), oysters and mussels (Gutiérrez et al., 2003) can improve the physico-chemical water conditions, reduce the physical stress (Arkema et al., 2013; Möller et al., 2014) and favour the establishment of associated biodiversity (Jones et al., 1994). Additional practices include the establishment of vegetated reinforcements, through the use of natural materials (e.g., bio-reeds; Pan et al., 2015).

In parallel to the structural improvement of coastal defence, so-called nature-based solutions are increasingly being implemented for climate change mitigation and adaptation (Nesshöver et al., 2017; Seddon et al., 2020). Natural and nature-based structures are designed by humans for coastal protection and mimic the environmental characteristics (Sutton-Grier et al., 2018). Nature-based solutions are ecosystem-based, and involve an umbrella of concepts and approaches. These include sustainability, community involvement, respect for cultural diversity, and embracing diverse knowledge (Cohen-Shacham et al., 2016) and have the scope to maintain and restore diverse and resilient ecosystems while providing critical services, biodiversity benefits, prosperity and human wellbeing (Davis et al., 2015; Sutton-Grier et al., 2018). Nature-inspired designs have often been used as a hybrid model, pairing civil engineering with intertidal planting of vegetation (Currin et al., 2018) or ecosystem engineers (e.g., oyster sills; Milligan et al., 2018) and they have mostly been successful in low energy environments (van der Nat et al., 2016). Examples of applications of such innovative urban management of the coast are the living shorelines (Smith et al., 2018; Sutton-Grier et al., 2018) which comprise practices that reduce energy onsite while ensuring the occurrence of the natural physical processes (O'Donnell, 2017) and improving nutrient fluxes (Onorevole et al., 2018). Nature-based techniques used for the development of living shorelines include the planting of native vegetation, use of organic, biodegradable material and concrete natural breakwaters like oyster reefs (Piazza et al., 2005) that can be seeded to enhance and make Indigenous ecosystem engineers self-maintained (O'Donnell, 2017).

Despite the increasing numbers of living and ecologically engineered shorelines projects worldwide, integration between ecological and engineering efficiency is still needed to ensure the best practices are biologically, ecologically and financially sustainable, hydrodynamically and cost effective and manufacturing durable (Morris et al., 2019). Furthermore, in marine systems, natural, nature-based, soft eco-engineering remains an emerging concept because even if there has been a proliferation of applying concepts of natural/nature-based solutions to coastal artificial infrastructures in the marine environment since the early 2000s, these applications have not really scaled-up nor have yet been implemented as routine practices (Evans et al., 2019). Globally, there have been a few examples of non-research driven implementation of natural/nature-based solutions (e.g., Toft et al., 2013; Scyphers et al., 2015; Perkol-Finkel and Sella, 2016; Naylor et al., 2017; Palinkas et al., 2022), however, most of the specific policies to encourage implementation of natural/nature-based are lacking outside of Europe (as discussed by Dafforn et al., 2015).

Nature-based solutions and communities

The integration of local knowledge, as well as community-participatory engagement that enables local economic and social empowerment is becoming common-place in management, conservation and restoration programmes of marine ecosystems (Lepofsky and Caldwell, 2013; Mathews and Turner, 2017; Lombard et al., 2019) although is often still subsumed within scientific practice rather than given equal recognition. Community-based management of ecosystems and resources has been proven successful in several cases, but varies substantially depending on the global or local nature of the arrangement, the sector and actors involved, and the specific landscape and history of the case in question (Wynberg and Hauck, 2014; Kairo and Mangora, 2020). Endeavours that integrate community involvement, Indigenous knowledge, access to equitable benefits and nature-based solutions for improving the quality and functioning of (urban) ecosystems are, however, still scarce (Gaspers et al., 2022). The most common efforts of community involvement revolve around nature-based (eco)tourism efforts (Coria and Calfucura, 2012; Bluwstein, 2017; Padma et al., 2022).

Building on centuries of cultural and biological co-evolution, Indigenous peoples and local communities have developed multi-generational knowledge that can hold often intangible, yet enormous value in the design and implementation of innovations that are innately "nature-based", imitating the structure and function of natural ecosystems. The involvement of local communities in supporting innovations to restore functionality of ecosystems is, however, still largely lacking (Gaspers et al., 2022; Reed et al., 2022). This gap, and lack of participation by Indigenous people and local communities, is concerning (Seddon et al., 2020) given the academic (and political) momentum of the nature-based solution concept, with global traction on practices to sustainably and innovatively address appropriate economic development while mitigating climate change, resolving biodiversity crises, and restoring the functionality of coastal systems (Cohen-Shacham et al., 2019; Hanson et al., 2020). There are numerous pitfalls in the application of nature-based solutions for ecological rehabilitation, many due to the fact that Indigenous peoples and local communities are not typically recognised as holders of knowledge that contribute towards these solutions (Rizvi et al., 2015; Cassin and Ochoa-Tocachi, 2021; Reed et al., 2022). Such pitfalls are aggravated when focus shifts from urban terrestrial or freshwater systems to marine settings, where sparse support is generally provided (Lepofsky et al., 2015; Nguyen and Parnell, 2019; Bryndum-Buchholz et al., 2022).

The failure to fully include Indigenous and local communities and associated knowledge in the co-creation of nature-based solutions, and the benefits that arise from them, is inimical to the growing prominence of nature-based solutions themselves in international climate and biodiversity policies, and links to Sustainable Development Goals (SDGs) of reducing inequality and poverty (Hanson et al., 2020; IPCC, 2021; One Planet Sustainable Tourism Programme, 2021; Post-2020 Global Biodiversity Framework, 2021). The rich and increasing evidence of local and Indigenous knowledges and practices that contribute directly to nature-based technologies and innovations provides compelling proof of the need to absorb them into programmes, policies and governance schemes (Cassin and Ochoa-Tocachi, 2021).

Indigenous peoples and small-scale farmers, women, fishers, pastoralists and forest dwellers continue to be custodians of 80% of the world's biodiversity, managing 28% of global lands, including more than 40% of protected areas (Garnett et al., 2018; Worsdell et al., 2020; https://www.iccaconsortium.org/). This connection is expressed in the relationships held with nature and related technological and engineering innovations (McGregor et al., 2020; Bielawski, 2021; Cassin and Ochoa-Tocachi, 2021). Recognising, maintaining and protecting these customs, practices and innovations is also underlined in commitments articulated in the Paris Agreement for sustainable governance (Brodie-Rudolph et al., 2020), the United Nations Declaration on the rights of the Indigenous People (UNDRIP) and the UN Declaration on the Rights of Peasants and other People Working in Rural Areas (UNDROP) and the recent Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) assessment on the sustainable use of wild species (Cohen-Shacham et al., 2019; IPBES, 2019; Ruckelhaus et al., 2020; Reed et al., 2022). It is clear that Indigenous and locally-led knowledge, governance and recognition of Indigenous people and local communities as rights-holders should be prioritised to achieve transformative and tangible environmental benefits provided by nature-based solution approaches (e.g., Seddon et al., 2021; Reed et al., 2022), yet the exclusion legacy continues.

Transgressive practices: Merging Indigenous knowledge, traditional creative expressions and scientific knowledge

To deeply recognise and value the active contribution of Indigenous knowledge, people and local communities towards culturally embedded principles of nature-based innovations, one must integrate disciplines outside the classic economic frame, for a sustainable advancement of the environmental protection and economic empowerment (Grant et al., 2021). As such, the fields of ecoacoustics, community music, ecomusicology can be used as a transgressive, interdisciplinary link between the scientific, cultural, creative and pedagogical research areas. In essence, a link must be established between local communities and scientific interventions that break traditional boundaries and experiment with ways of teaching and learning that foster recognition of Indigenous cultural values and human expressive output. The transformative, transgressive forms of learning taking place require engaged forms of pedagogy that involve multi-voiced interaction with multiple actors. This approach has an emphasis on co-learning, cognitive justice, and the formation and development of individual and systemic agency. We ask if human civilisation, which is essentially guided by culture and heritage, threatens the ecosystem then where are those uniquely human disciplines, such as the arts and humanities, in the process of solution development, understanding, education and struggle (Allen, 2012)? Ecomusicology, a sub-genre of ethnomusicology can be defined simply as the critical study of sound and environment (Allen and Dawe, 2015) and was initiated as a field in Europe during the 1970s in order to stir interest in the relationship between humanity and the natural environment (Allen, 2011). It has developed to encompass any environmental study through the perspective of traditional cultural expressions (TCEs), but particularly relates to researching environmental questions of direct public relevance from a musical perspective (Allen, 2012). A more elaborate definition of ecomusicology is that it is a critical study of music and the environment which considers the interconnections between sound, nature and culture (Challe, 2015; Feisst, 2016). In the field of ecomusicology, there are critical environmental questions that have led musicologists, ethnomusicologists, popular music researchers, musicians, producers, anthropologists, sociologists and scientists to give focus to common areas of interest (Pedelty, 2013). The significance of this transdisciplinary research is timely as it supports the balanced approach that understands environmental problems as also having cultural underpinnings and solutions (Allen, 2012). The eco-creative process applied through an ecomusicological lens aims at using TCEs collected and developed, and the scientific output as co-created material for teaching and learning. The goal is to revalue through educative resource development Indigenous knowledge and heritage practices, which are historically neglected (Allen, 2012; Allen and Dawe, 2015).

Culture can be seen as a product of human behaviour, and thus it is important that behaviour is also looked at when dealing with the environment. Gosling and Williams (2010) write that one of the ways of achieving the task of changing behaviour, is through promoting dialogue and creating a new culture of recovering and publicising the dissemination of cultural and environmental heritages to encourage a sense of the environment belonging to the community. This can yield positive results because when people have a level of connectedness with nature they tend to have a greater and more connected environmental concern (Gosling and Williams, 2010). Thus, through active reflection of self, the community can engage with their environment as a cultural asset, interact with the Indigenous knowledge through creative output and therefore promote a drive for environmental custodianship (Impey, 2006). Examples of these types of interdisciplinary interventions include Pedelty et al.'s (2020) "Field to Media" co-creation of five different music videos to address a range of pressing environment related matters in USA/Canada, Tanzania, Bangladesh, China and Haiti (Worm et al., 2021); the Canadian freely available audiovisual resource called Ocean School (http://oceanschool.ca) which uses a combination of visual storytelling, scientific inquiry and Indigenous knowledge to foster ocean literacy and engagement; Rothenberg's (2008) duet with a Humpback whale; and, in South Africa, work done by Empatheatre (https://www.empatheatre.com) which is a collaborative, documentary theatre process that is being used by researchers to open up generative dialogue on complex issues and sources of conflicts about the ocean to offer potential methodological innovation in public consultation through storytelling and theatre performance. At this stage, however, there is little evidence of more eco-creative ocean-based pedagogy being produced in Southern Africa.

The South African case study

The next section of this review provides a regional perspective and elaborates on certain concepts that frame a recent South African case. While local circumstances drive best practices and approaches, we believe that this example from the Global South is especially important to address some of the gaps identified in the previous section of the paper, in order to bridge boundaries. Here, we hope to offer an alternative and original opportunity to reflect on transdisciplinary participatory research on nature-based ecological engineering of the coastal environment. This regional perspective funnels notions of cherishing the multiple benefits of equitable social inclusion through the co-creation of both scientific and creative TCEs, in order to attain effective and sustainable research and governance practices for ecological engineering endeavours aimed to enhance urban coastal functionality and ensuring human wellbeing.

The Indigenous Marine Innovations for sustainable Environments and Economies (IMIsEE) project

In South Africa, pressure on marine biodiversity has been recognised as a major concern due to the intensifying of human activities, including coastal urbanisation (Mead et al., 2011; Department of Environmental Affairs, 2015; Classeens et al., 2022). One of the most worrisome and obvious challenges of a loss of coastal biodiversity is the threat to food security, especially in light of Operation Phakisa, the most recent governmental enterprise that aims to unlock the blue economy of the Republic (www.operationphakisa.gov.za; DAFF, 2014). Operation Phakisa's narrative has thus far attained modest economic results (Walker, 2018) and through its focus on economic growth, minerals and oils exploitation, seismic exploration, harbour development and aquaculture, seriously threatens marine biodiversity and undermines the livelihoods of local coastal communities (Carroll et al., 2017; Pichegru et al., 2017; Bond, 2019; Andrews et al., 2021). Despite a national prioritised focus on ecosystem-based resources and identification of services hotspots (Davids et al., 2016), most management plans for harbours (large and small) touch only remotely on the preservation of biodiversity. Rather, efforts are directed to the biological monitoring of indicator species in relation to threats to sediment (e.g., effects of accumulation of heavy metals and organic compounds; Fatoki et al., 2012; Kampire et al., 2015), water and sanitation (especially for estuarine ports with direct discharges from cities and agricultural runoff; Mema, 2010; Olarinan et al., 2015), with recent concern about the impacts on marine ecosystems from sea mining (Republic of South Africa White Paper, 2014; Currie, 2015).

The value of biodiversity-associated Indigenous knowledge has increasingly been recognised through international agreements such as the UN Convention on Biological Diversity and its Nagoya Protocol which sets up a legal framework requiring access and benefit-sharing arrangements to be negotiated between users and providers of genetic resources and associated traditional knowledge (Secretariat of the Convention on Biological Diversity, 2011). In South Africa, government has recently promulgated an Indigenous Knowledge Systems Act (6 of 2019) that sets out the framework for the protection, promotion and management of the rights of bearers of Indigenous knowledge. The act also includes details for the establishment and functions of the National Indigenous Knowledge Systems Office (NIKSO) to assist with commercial use of Indigenous knowledge and cultural expressions. The re-naming and re-branding of a central governmental department from the Department of Science and Technology (DST) to the Department of Science and Innovation (DSI) underlines the national shift in emphasis towards research and technological innovations to support economic development. The production of innovative applications, embedded within Indigenous knowledge (IK technoblending; Mwantimwa, 2008), is well suited for a context such as South Africa, where rural communities mostly rely on traditional expressions and practices (Jauhiainen and Hooli, 2017). The strategy also supports the potential for scaling-up innovative Indigenous approaches and could assist in empowering local communities and providing much needed new sustainable economic opportunities (Hooli and Jauhiainen, 2018). Although considered economically marginal and typically ignored in national decision-making (Shackleton, 2009; Laird et al., 2010), plant material is often used for craft making (weaving), and is an important element for rural communities, in terms of livelihoods, Indigenous knowledge and heritage (Kepe, 2003; Makhado and Kepe, 2006; Traynor et al., 2010; Kotze and Traynor, 2011).

Within this framework, and in an attempt to fill some of the gaps articulated in this paper, a new, nonconforming research project (2022–2024) funded by the South African National Research Foundation, takes inspiration from both scientific and Indigenous synergistic practices to forge a collaborative partnership between scientists and members from a local rural community (Hamburg, Eastern Cape Province, Figure 1). Through the project, *Indigenous Marine Innovations for sustainable Environments and Economies (IMIsEE project),* natural woven biodegradable structures are co-created to retrofit the built coastal environment (small and large harbours) as well as two control natural rocky shores and tested for their short- to mid-term ecological functional value for early stages of marine species in urban settings located along one of the poorest provinces of South Africa, the Eastern Cape (Figure 1). The merging of scientifically innovative, eco-creative approaches and TCEs has the potential to sustainably and ethically improve the functioning and diversity of these urban habitats. As reviewed in this paper, testing of innovative nature-based designs to improve their surrogacy for natural marine organisms to thrive requires attention in coastal ecology. Yet efforts to undertake such testing are still limited, especially in developing economies (Shackleton et al., 2021). Often, rural coastal communities are neglected, and left marginalised, at the expense of urban development, governance or blue economy initiatives (Cohen et al., 2019; Isaacs, 2019). The *IMIsEE project* takes a much needed holistic approach that aims to combine urban and blue economy development, which often only has one tier, economics, with the needs of traditional rural communities (in the form of Indigenous knowledge and job creation), as well as increased biodiversity and ecological functionality in urban coastal ecosystems.

Community participatory action: Benefit-sharing for real rural empowerment

The material used to co-design and manufacture the nature-based structures for the *IMIsEE project* is the grass-like sedge *Cyperus textilis* (Cyperaceae), locally known as *imizi.* This fibre is widely used by artisanal crafters, mostly women (Makhado and Kepe, 2006), in the rural areas of the Eastern Cape Province in South Africa (Figure 1), to weave traditional sleeping and sitting mats as well as baskets and serving trays (Fukweni, 2009; Figure 2). Indigenous knowledge and specialised skills are required for the successful crafting of the woven structures required for this research and used to retrofit the built coastal environment. As such, women within the community, who are the traditional knowledge-bearers of the weaving practice, have the greatest influence throughout the project and will be the most empowered. Currently five women crafters (the number is likely to double) are involved in the production of the woven nature-based structures for the research, with the price per unit established through fair cost price analysis with representatives of the community.

The application of Indigenous knowledge for the co-creation of these low-tech, easily reproducible nature-based substrate alternatives may hence serve the bio-enhancing ecological needs while reducing social, especially gender-based, inequalities and alleviating poverty. Through the project, this innovation is already providing some economic upliftment to the second poorest province

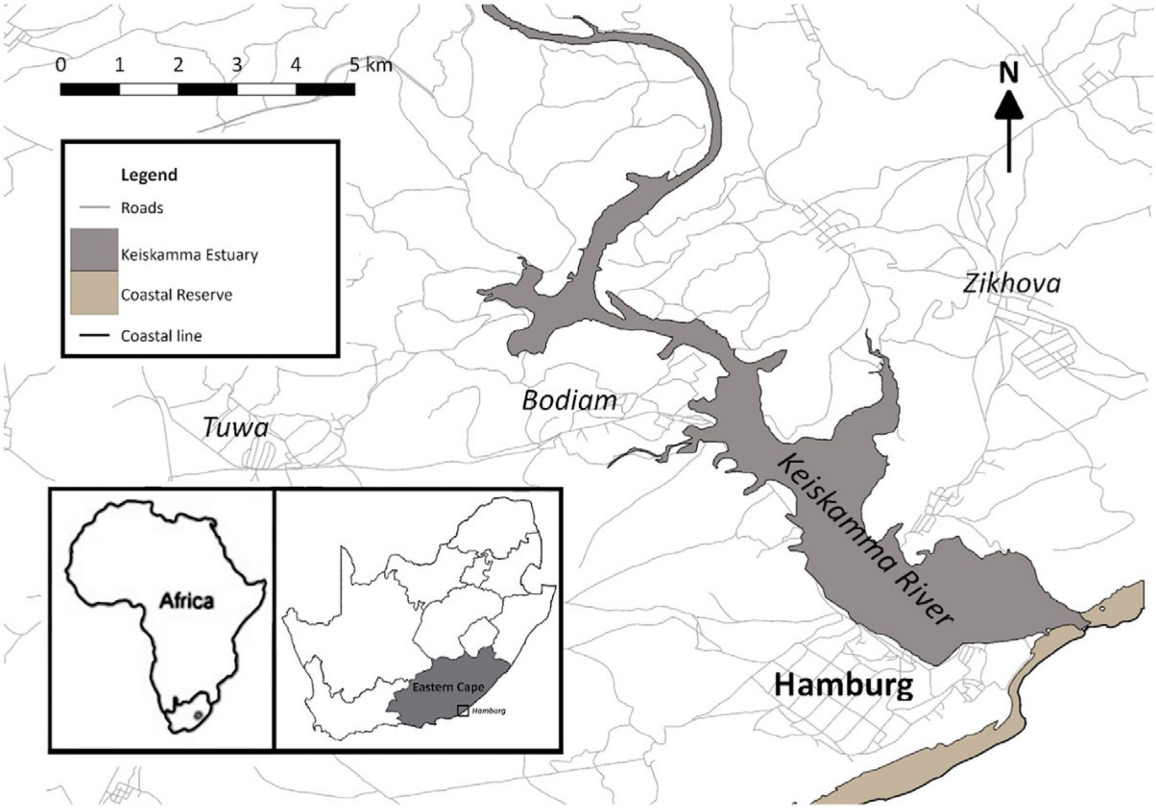

Figure 1. Geographic location of the Eastern Cape Province, where a component of the IMIsEE project is conducted, as well as the village of Hamburg, where the rural community is based.

Figure 2. Examples of woven crafted objects made using the plant *Cyperus textilis*, locally known as *imizi* (photo by: Francesca Porri).

in the country and the worst national unemployment rate (47.1%), directly improving the income of several households within the Hamburg community and placing traditional knowledge bearers, mostly women in this case, at the epicentre of this creative production. Given that the artisanal practice of weaving is a dying practice, the intention is for the *IMIsEE project* to boost the heritage value of this local innovation while providing a benchmark for the direct (and potential future) economic empowerment of the rural Hamburg community, while ensuring active and valued participation of local communities as co-creators of innovative science and promoters of principles of conservation of coastal biodiversity.

Inclusive, democratic engagement with community partners to co-create the nature-based innovation is of primary importance and forms the foundation of this research. The 76-4project builds on a novel collaboration among three main institutional partners from the Eastern Cape Province in South Africa, namely the community-lead Keiskamma Trust, The National Research Foundation government facility, The South African Institute for Aquatic Biodiversity and the tertiary research and training institution, Rhodes University. The Keiskamma Trust is a non-governmental organisation (NGO) established in 2002, which aims at supporting vulnerable social groups. This NGO has a long lasting trusted relationship with the local communities around Hamburg, Eastern Cape, South Africa (33.2823°S, 27.4263°E; Figure 1). This reliable connection has been fundamental for facilitating the crucial engagement steps included in the first objective of the project ("Community participatory action and Indigenous pedagogies"), such as the selection of community participants (including ensuring gender equality), obtaining prior informed consents, and the drawing up of the necessary Memoranda of Understanding (MoU; see details below). The collaboration is ongoing and strengthened through a series of community engagements to help co-design nature-based structures and implement the project, and it was signed by an *imbizo* (gathering) during the first year (August 2022), where key representatives of the community and knowledge bearers gathered to sanction the project and co-participation. Sourcing of the woven nature-based structures has been signed by entering academic-community memoranda of agreement and Code of Practice (informed by the Global Code of Conduct for Research in Resource-Poor Settings; Schroeder et al., 2019), which includes drafting of *Isi-Xhosa* (the prevalent language in the region) translated informed consent for the key knowledge bearers, woman

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artisanal crafters. A key part of this innovation stems from the partnership between researchers and crafters, which is characterised by ongoing conventional and *ad-hoc* conversations as well as structured workshops, trials, the in-field deployment and retrieval of nature-based structures and the drafting of intellectual property agreements for potential commercialisation. This agreement ensures protection of this Indigenous innovation, while empowering local entrepreneurship. Depending on the success of this initial testing phase, the potential upscaling for commercialisation and hence patenting may be considered for large-scale positive income creation. Background consideration of intellectual property in the context of Indigenous knowledge has therefore also been carefully considered and transparently reflected into the MoU completed with the community collaborators and beneficiaries. Again, depending on the outcomes of this experimental pilot phase, scaling up may lead to uptakes by local industry stakeholders (Transnet National Port Authority [TNPA]) and policy makers (Department of Environmental Affairs). Importantly, the Indigenous knowledge bearers will be the direct beneficiaries of this innovative co-creation as well as recognised as knowledge-creators.

Indigenous pedagogies

As a link to sustainable knowledge development and community enrichment, the scientist- rural community partnership within the *IMIsEE project* also includes ecomusicological interventions. Ecomusicology is a key approach for this research and considers the relationships between culture, nature, music/sound, humans and to cross transdisciplinary boundaries. For Allen (2012), the educational benefits of ecomusicology include six key areas in the field: ecology and acoustic ecology/sound-scapes, biology and biomusic, anthropology and ethnomusicology, history and musicology, and sustainability and cultural studies of music. As one of the few ecomusicology projects currently underway in South Africa, a large part of this research is the exploration of the parameters of ecocritical musicology evaluated through TCE representations, including sounds, songs, music, fables, life-stories, handicrafts and individual narratives. This collection of TCE will be disseminated using various sonic approaches such as digital story-telling, podcasts, film documentaries, plays, poems, songs and digital soundscapes, co-created by the scientists, community members and musicians. Impact is expected to result in a sustainable interest in the community's role in maintaining an ecologically efficient coastline as well as establishing the importance of Indigenous knowledge systems as a contemporary agent in societal reinvigoration. These outcomes will further create opportunities for transgressive teaching and learning (Allen, 2012; Lotz-Sisitka et al., 2015).

Indeed, our vision for inclusive and sustainable Indigenous performing arts pedagogies builds on transgressive learning. Through transgressive and eco-creative learning approaches, in parallel to the co-creation of the nature-based structures, researchers regularly engage with knowledge bearers, educators and learners to generate new forms of eco-knowledge and learning material through the science, arts and music. Researchers closely document testimonials throughout the co-design, manufacturing and testing of the nature-based structures. These interactions form the core mediators among all objectives of the research and will be translated into shared TCEs as transgressive pedagogical tools for communicable science. Transgressive eco-creative pedagogical intervention are aimed to empower the community and revalue Indigenous ways of knowing and being by giving the knowledge bearers agency as well as by disseminating the developing knowledge in accessible and creative ways. The value and sustainability of this kind of knowledge and pedagogical approach is incalculable. Pedagogically, the development of Indigenous and transgressive learning approaches adds to the emerging data on STEAM (Science, Technology, Engineering, Arts and Mathematics) learning education, a proposed goal of curriculum development (Barajas-López and Bang, 2018; O'Connor, 2020).

Knowledge production and dissemination in research have long treated local communities as informers rather than knowers and knowledge producers themselves (Lund et al., 2016; Lepore et al., 2021; MacLean et al., 2022). A fundamental problem is that South African educational structures inherited from colonialism are based on cultural values different from those existing in most African Indigenous societies, where education is still conceived through marginalising Indigenous cultural values and ways of teaching and learning into the education system at all levels (Masinire, 2020). Using "call-and-response" singing in Africa as a metaphor, this research develops co-creating praxis in active pedagogy innovation by combining arts-based pedagogies and action research. The tradition of "call-and-response" singing, where a lead performer interacts with answering musicians, is deeply embedded in knowledge co-production as it values the relationships among people. This tradition is being translated in our project as valuing the relationship between nature and culture, between people and the ocean, between researcher and community, between heritage and innovation. One cannot exist without the other.

In addition, the research through the *IMIsEE project* supports the National Research Foundation Vision 2030 in addressing the strategic beacons of Transformation, Impact, Excellence and Sustainability (TIES; https://www.nrf.ac.za/wp-content/uploads/2021/03/NRF-Vision-2030_0.pdf). Through active, participatory community involvement, the promotion of gender equality, the implementation of transversal and experiential education practice, and sustainable, innovative outcomes, the *IMIsEE project* will produce sustained impact through responsibly driven, innovative transdisciplinary research, including the fields of science, music, heritage and Indigenous knowledge production and revaluation. This strong community-science tier has the ultimate potential to regenerate the coastal environment, while prospering human wellbeing and economic development. This delicate, yet much needed endeavour provides an example of how scientific Indigenous knowledge-based innovations can foster transformative change and reconcile the socio-economic, heritage and conservation interests in coastal systems, for the wellbeing of humankind and the strengthened resiliency of nature and society. Deeply founded in a TIES framework, through a nature-based solutions approach, the project ultimately tackles the intricate synergies of conservation of marine biodiversity, mitigation of the effects of coastal urbanisation and social needs.

Conclusions

We regard this South African case study as an innovative and path-breaking regional roadmap that fills several of the gaps identified in this paper. It offers opportunities to shift mind sets and in doing so change narratives of research agendas in order to better integrate the needs of both the environment and people (Kelly, 2018). Through this paper and further research, an integrated outcome will be developed that holistically covers several dimensions and standards: implementation of novel designs, evidence-based quantification of methodologies, enhancement of coastal biodiversity,

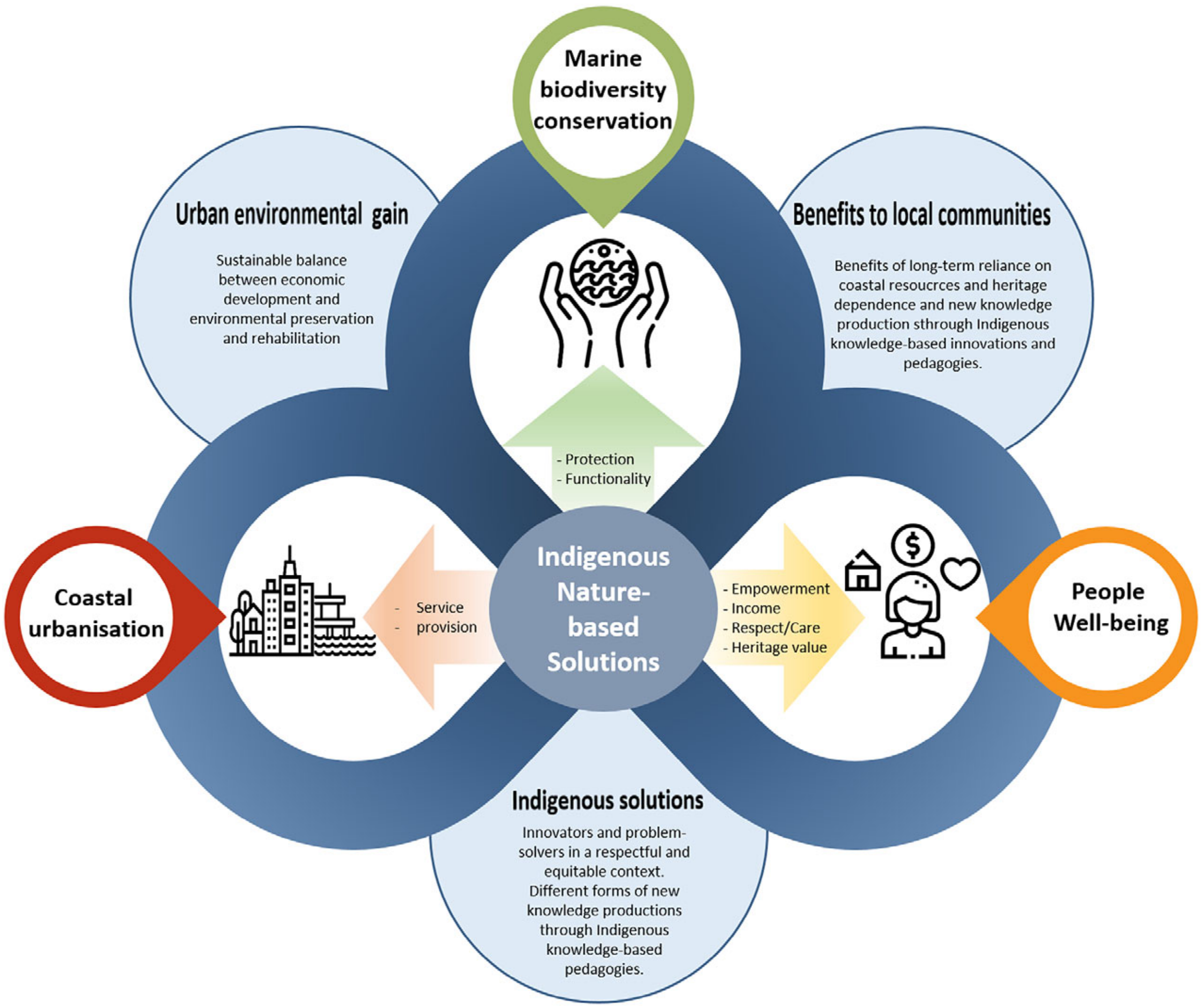

Figure 3. Integrated holistic framework for research on Indigenous nature-based solutions applied to coastal systems that covers multiple dimensions (coastal urbanisation, marine biodiversity, people) and gains (new designs; environmental gain; benefits to local, Indigenous communities).

alignment of functionality of coastal urban systems, integrated action and assimilation of Indigenous knowledge, practices, legitimacy, derived pedagogies and cohesive safeguarding and respect of Indigenous People and local communities (Figure 3). Given the early stage of the project, we acknowledge the many risks and challenges that will result from its implementation, hence unlocking a further platform for lessons learnt, but we trust this perspective is timeous and valuable. While pioneeringly ambitious, we believe this inclusive and transparent framework is necessary to create new knowledge for a sustainable, long-term and empowering resolution of nature–human conflicts, which could further assist in shifting towards meaningful environmental perspectives, strategies, policies and good governance.

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Competing interest. The authors declare no competing interests exist.

Ethics standards. Although the paper does not present unpublished data, the IMIsEE project is covered by animals (RU- 2022-5423-6632 – and SAIAB-25/4/1/7/5_2022–04 – Animal Ethics Committees) and human (RU- 2022-4951-6722) ethics applications.

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